# INFLUENCE OF PRODUCTION LIGHT LEVELS, FERTILIZER REGIMES, MOISTURE STRESS CONDITIONING, UNICONAZOLE AND RETAIL WATER REGIMES ON THE LANDSCAPE PERFORMANCE OF CATHARANTHUS ROSEUS 'COOLER PEPPERMINT'

By

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1997

ACKNOWLEDGMENTS

The author would like to thank the members of his committee, Drs. Jim Barrett, Terril Nell, Edward Gilman, Kimberlyn Williams and Jerry Bennett, for giving someone that could only pursue his graduate work on a part-time basis a chance to do so and for believing that I could accomplish my goal. As someone who counts learning as one of the great pleasures in life, I thank all of my professors for sharing their knowledge, skills and philosophies and for serving as role models for my own teaching career.

A very large feeling of gratitude is extended to everyone who works behind the scenes in the Environmental Horticulture Department to make learning and earning a degree possible, including Mary Ann Andrews, Carolyn Bartuska, Jackie Host, Candy Kellinger, Ria Leonard, Marie Nelson, Bart Schutzman, Robert Smith, Bob Weidman, Diane Weigle and Judy Wilson. I would also like to acknowledge Dr. Dennis McConnell and Bodie Vladimirova for assisting me with my anatomical work and for allowing me to use their laboratory space.

I count my experiences with the many graduate students with whom I met and worked with as one of the true rewards of pursuing a graduate degree and thank them for their assistance and fellowship.

Finally, none of this work would have been remotely possible without the supportive foundation provided by my wife, Cathy, my family and University Lutheran Church.

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December, 1997

Chairperson: Dr. James E. Barrett
Major Department: Environmental Horticulture

A series of experiments were conducted to evaluate and quantify the effects of production light levels, fertility rates, moisture stress conditioning, uniconazole concentration and spray time and retail watering regimes n the landscape growth of Catharanthus roseus `Cooler Peppermint' under different landscape fertility levels.

Single seedling plugs were planted into 10-cm containers. Two production light levels of "high" (1,550 $\mu$mol $m^{-2}$ $s^{-1}$) and "low" (1,025 $\mu$mol $m^{-2}$ $s^{-1}$), two production fertility concentrations of "low" (50 ppm N) and "high" (150 ppm), five moisture stress conditioning levels during production of "WW" (well watered), "LW+1"(well watered until the last 2 weeks of production then allowed to wilt for 1 day between waterings),

"W+1" (allowed to wilt for 1 day between waterings), "W+3" (allowed to wilt for 3 days between waterings) and "WW+Uniconazole" (well watered, treated with uniconazole), two uniconazole treatment times during production of "week 3" (3 weeks after plug transplanting) and "week 5" (5 weeks after plug transplanting), five uniconazole concentrations of 0, 1, 2, 4 and 8 mg liter$^{-1}$, two retail watering regimes of "WW" and "W+1" and two landscape fertility levels of "low" (0.38 lb. N/1000 ft$^2$) and "high" (1.5 lb. N/1000 ft$^2$) were researched.

Light microscopy procedures were undertaken to evaluate treatment effects on stomatal densities, total stomata per leaf and leaf cell dimensions and arrangements. Physiological parameters investigated included stomatal conductance, transpiration per unit leaf area, osmotic adjustment and turgor loss points. Changes in plant height, width and size were determined at the end of greenhouse production and every 2 weeks in the landscape. Days to flower, flower diameters, leaf areas and root:shoot ratios were measured at the end of production. Shoot dry weights were determined at the end of production and after 6 weeks in the field.

The research showed that Catharanthus will grow best in a landscape when fertilized during production with 50 ppm N , given a "W+1" production water regime, maintained well watered in the retail setting and planted in a landscape bed in full sun that is maintained well watered and receives 1.0 lb. N/1000 ft$^2$/month. If a chemical growth retardant is to be used in lieu of the "W+1" regime, uniconazole between 2 and 4 mg liter$^{-1}$ should be applied to foliage 3 weeks after plug transplanting.

# CHAPTER 1
# INTRODUCTION

Gardening has become America's number one past-time. Eighty percent of US households undertake some form of gardening (Ball, 1996). This activity creates an enormous demand for plant material and related supplies. In 1995 floriculture crops generated $3.27 billion of wholesale sales in the US, up 1% from 1994 (Osborne, 1996). The wholesale value of bedding plants in 1995 was $1.32 billion, up 3% from 1994. Florida, the number two floriculture producer, generated $613 million in sales, up 2% from 1994. Bedding plants represent the fastest growing sector of the floriculture industry. In spite of these impressive numbers, it has been reported that as much as 20% of floriculture products become unsalable, damaged or reduced in price after grower production (Armitage, 1993). One could only wonder what the floriculture sales figures would be if the plants were more attractive at the retail outlets and performed better in landscape situations. As far back as the 1970s improved marketing and customer satisfaction were stated as requirements for continued growth and expansion of the bedding plant industry (Voigt, 1979). Apparently not much has changed in nearly 20 years since Armitage stated that "This potential loss of confidence in our product (due to poor retail and landscape performance) is the single most important factor that can undermine the floricultural industry" (p. 3). Producing plants that can retain their quality

under potentially adverse retail sale and landscape conditions is more necessary than ever to sustain and increase the market for bedding plants. In particular, producing bedding plants in a manner that improves their performance under drought or drought-like conditions can aid in further increasing the demand for these plants.

Much research has been done in the areas of crop breeding and environmental production conditions to assist bedding plant growers in efficiently producing an attractive and profitable crop. However, very little data exist to demonstrate how production techniques affect the postproduction performance of bedding plants once they leave the greenhouse.

The objective of this study was to investigate how production conditions affect the postproduction performance of bedding plants. Specifically, the roles of production light levels, watering regimes, fertilizer concentrations, growth regulator applications and retail water regimes were studied to determine their effect on the performance of Catharanthus roseus 'Cooler Peppermint' in landscape bed settings. Anatomical and physiological procedures were implemented to characterize the effects of production conditions on leaf size and structure, stomatal density, stomatal conductance, leaf water potential, transpiration, osmotic adjustment and turgor loss points. These research parameters were selected because of their interactive role in affecting plant water relations and photosynthetic capacities. Plant growth and flowering were also monitored during production and postproduction phases. Developing protocols for the efficient, environmentally sensitive and profitable production of bedding plants that will perform more satisfactorily in retail and landscape settings was the ultimate focus of this research.

# CHAPTER 2
# LITERATURE REVIEW

## Selection of a Research Model Plant

Catharanthus roseus (L.) - Madagascar periwinkle, Apocynaceae, was selected as the model plant to study in this research project. The plant is commonly referred to as periwinkle or vinca in the landscape and gardening trades. As the first common name implies, it is native to Madagascar which is in USDA hardiness zone 10 (Griffiths, 1994). Catharanthus grows as a shrubby perennial reaching heights of 60 cm. The leaves are elliptic, entire, grow between 2.5 and 5.0 cm long and possess a glabrous and glossy surface. The flowers are actinomorphic with five nonoverlapping to slightly overlapping petals that are arranged in a whorl fashion to form a perfect circle. Flower colors range from pure white to all shades of violet, rose and red. Some are white with rose centers or "eyes."

As a bedding plant, periwinkle is used for seasonal color during the warm months of the year. It is killed by a frost but can reseed itself in semitropical and tropical climates, where it can become invasive. The plant thrives in moist, well drained soils, tolerates salt and prefers full sun. It can be susceptible to root rots in soils with poor drainage or if overwateredDue to recent breeding efforts that have produced more compact plants and new flower color ranges, periwinkle's popularity and thus importance as a bedding plant is

quickly rising (Beytes, 1996). It is now one of the top ten bedding plants produced and sold in the US.

As a research plant, periwinkle's heat tolerance readily lends itself to both greenhouse and outdoor conditions common to Florida's spring and summer seasons. Its growth habit and leaf structure make anatomical and physiological measurements simpler and reliable as compared to other species of bedding plants. Due to the importance of Catharanthus's natural alkaloids for cancer treatment, some basic research on its water relations has already been completed (Virk and Singh, 1990). A limited amount of research has also been conducted on greenhouse production parameters for periwinkle as well (Pietsch et al., 1995).

## Water Relations of Bedding Plants during their Life Cycle

Most species of plants used as bedding plants in the landscape and gardening industries are mesophytes. These plants rely on constant access to intermediate levels of moisture in order to complete their life cycle in an efficient and productive manner. Lack of water to bedding plants, leading to plant stress, can be caused by small volumes of media in the root zone, low water holding capacity of the media, lack of moisture supplied to the media, poor root development, damaged roots or high evapotranspiration rates due to rapid air movement, high light, high temperatures and/or low relative humidity (Armitage, 1993). In order to maximize growth rates and thus profits, producers of bedding plants usually avoid stressing the plants by supplying optimum water during production. It has been standard practice, however, to reduce the watering frequency at the end of

production to "harden" the plants for shipping and market. Due to improper manipulation of light and temperatures as well as less than optimum watering, bedding plants more often than not experience slight to severe water stresses at the retail setting. These stresses often result in a poor quality plant. Likewise, many bedding plants experience water stress once installed in the landscape or garden, resulting in less than desired landscape performance. The relevant issue, then, is whether production practices are helping or hindering the plant's ability to conserve water in retail and landscape settings where adequate water is often lacking.

## Postproduction Performance as Related to Production Practices: Nonbedding Plant Floriculture Crops

Much research has been conducted that shows cultural production practices can have dramatic effects on how well plants perform in postproduction situations. The appearance of container grown Ficus benjamina and Brassaia actinophylla that had been in an interior environment for 10 weeks was superior for plants that had been previously acclimatized under 40% or 80% shade for five or more weeks as compared to plants grown in full sun (Conover and Poole, 1975). 'Amy' and 'Annette Hegg Dark Red' poinsettias, Euphorbia pulcherrima, lost fewer leaves under interior conditions when the plants were shifted to low light intensity (300 $\mu$mol $m^{-2}$ $s^{-1}$) one or three weeks prior to being moved to interior conditions versus staying under high light intensity (500 $\mu$mol $m^{-2}$ $s^{-1}$) until being moved to interior conditions (Nell and Barrett, 1986). Christmas begonias, Begonia spp., grown under low relative humidity (50%) and high light intensities (10,000 lx) were found to

produce plants that had the highest sale time quality as well as keeping quality (Fjeld, 1986). Chrysanthemum plants fertilized with 100% nitrate form fertilizer lasted 10 days longer than plants receiving 100% ammonia form nitrogen fertilizer (Roude, 1988). Propagators of plants via tissue culture must acclimate the plantlets to more harsh environments than what the plants experience in vitro. Much research has been conducted that shows this successful acclimation (Bennett and Davies, 1986; Donnelly and Daubeny, 1986; Gmitter and Moore, 1986; Preece and Sutter, 1991; Simmons, 1984; Zhang and Davies, 1986). Diaz-Perez et al. (1995) concluded from their studies that the water relation characteristics and acclimatization issues of tissue cultured plants are not fundamentally different from that of plants grown out of culture. Experiments cited above indicate that plants can be successfully acclimated during production, thus enabling them to perform more satisfactorily in postproduction situations.

Postproduction Performance as Related to Production Practices: Bedding Plants

The research that has been conducted specifically on bedding plants has been limited and has mainly focused on studying cause and effect relationships at the applied level. Little research has been conducted on the physiological mechanisms or anatomical changes that may be responsible for these results. A general overview of what applied research has been done will be presented before a more in depth review of the physiological and anatomical literature is given.

Nelson et al. (1980) found that the keeping quality of both Tagetes and Impatiens was improved when plants were grown under a greater temperature variation between day and

night. It was suggested that the night temperature be lowered prior to shipping.

A low frequency of irrigation during production was found to increase the postproduction life of Petunia compared to a high frequency (Armitage, 1986). Crops of petunia and verbena produced under a constant low moisture level were found to have a low ornamental value at marketing stage (de Graaf-van der Zande, 1990). However, the same plants showed an excellent level of regrowth and longevity after being planted outdoors.

The fertilizer regime under which the bedding plants are produced can affect plant development in the greenhouse and postproduction performance. Petunia that received constant 100 ppm N fertilizer until anthesis exhibited increased postproduction life compared to plants that received no fertilizer once visible bud stage occurred (Armitage, 1986). Nell et al. (1994) found a similar result with geraniums. Pelargonium that received continuous greenhouse fertilization (150 ppm N) produced more flowers when transplanted into landscape beds as compared to those plants that received no fertilizer for 1 to 3 weeks prior to flowering in the greenhouse. In the same study, the growth of Catharanthus, Salvia and Impatiens was reduced when greenhouse fertilization was terminated for more than 1 or 2 weeks prior to flowering. After 6 weeks in the landscape beds, Catharanthus overcame the effects of reduced fertilization during production. However, for Salvia and Impatiens, their landscape growth was less when greenhouse fertilization was terminated 3 or 4 weeks prior to flowering compared to the controls.

In addition to fertilizer termination timing, fertilizer application concentrations and sources used during production play an important role in the ability of plants to handle

postproduction stress. Armitage (1993) reported that increasing fertilizer levels during production decreased the survival of marigolds in simulated retail environments. Jacques et al (1992) found similar results with Tagetes and Impatiens. They showed that fertilizing marigolds and Impatiens in soil and soilless media with nitrogen levels greater than 100 mg N/L did not improve overall growth but did reduce shelf-life. This nitrogen rate also yielded the greatest number of flowers on Tagetes. In terms of landscape establishment, Dufault (1986) found that Cucumis melo transplants conditioned with increasing nitrogen rates in the greenhouse had more severe transplant shock than those conditioned with low nitrogen. Dufault did, however, go on to report that the negative consequences of higher nitrogen levels could be lessened by increasing the phosphorous and potassium levels. Conversely, the root growth of Lycopersicum transplanted into the field was found to increase with each increasing level of N (up to 350 mg liter$^{-1}$) supplied in the greenhouse (Liptay and Nicholls, 1993). High nitrogen levels are known to promote shoot growth over root growth in many crops (Masson et al., 1990, 1991; Tremblay and Senecal, 1988). Masson's study showed that Lycopersicum was an exception to this trend, which quite likely accounts for Liptay and Nicholl's findings. It has been shown that transplants with well developed root systems recover more quickly from transplant shock (Weston and Zandstra, 1986). This finding suggests that a high root:shoot ratio is more desirable outcome for transplant production. Thomas and Latimer (1995) reported that root development was the critical factor in the production of high-quality Catharanthus. Thomas and Gilbertz (1992), with Latimer (1995), also showed that a high $NO_3^-$ to $NH_4^+$ N ratio, a micronutrient source in the sulfate form, a soil pH near 5.5 and the use of a high

porosity peat-based rather than bark-based mix enhanced Catharanthus root growth during production. Therefore, the level and source of nitrogen supplied to bedding plants during the greenhouse production phase must be considered as an important factor in the future landscape performance of those plants.

Plant growth retardants are routinely used in the production of bedding plants to control plant size. This control of size not only can improve the appearance of the plants, but can also aid in their shipping and marketing (Armitage, 1993). Research has been conducted that shows both positive as well as negative effects of growth retardants applied during production on postproduction performance. For example, Verbena sprayed with paclobutrazol and uniconazole showed reduced stem growth in the greenhouse as well as improved performance in the landscape due to reduced lodging (Davis and Andersen, 1989). Daminozide has been reported to extend the shelf life of bedding plants (Seely, 1985). The effect of growth retardants on flowering time has been found to be quite variable. Early flowering of Perlargonium was found to be enhanced by plant growth regulators (Latimer and Killingsworth, 1988). Zinnia flowering time was not affected by paclobutrazol (Cox and Keever, 1988) or by ancymidol (Armitage et al., 1981), but was found to be delayed by daminozide (Armitage et al., 1981).

Growth retardants applied in the greenhouse have also been demonstrated to yield negative effects on the growth rate of Zinnia, Impatiens and Tagetes in the landscape (Latimer, 1991). Zinnia sprayed with paclobutrazol or ancymidol in the greenhouse showed reductions in height 7 weeks after being transplanted into the landscape. Zinnia sprayed with daminozide or subjected to wilt cycles in the greenhouse showed no carry

over effect in the landscape. Impatiens sprayed with paclobutrazol in the greenhouse showed reductions in height and quality 7 weeks after being transplanted into the landscape. Impatiens sprayed with daminozide or subjected to wilt cycles in the greenhouse showed reduced width and quality after 5 and 7 weeks in the landscape. Ancymidol was found to have no effect on the landscape performance of Impatiens. Shoot dry weight gain of Tagetes was found to be reduced during the first week of landscape establishment by daminozide, ancymidol or water stress. Tagetes sprayed with 40 ppm paclobutrazol, 5000 ppm daminozide or 200 ppm ancymidol showed decreased final quality. However, there were no differences found in the final heights or widths of the Tagetes from any of the greenhouse treatments. This finding indicated that the growth retardant effects had disappeared by the end of 7 weeks in the field.

Studies have been conducted that show an increase in container volume can delay the onset of wilting and thus potentially improve the performance of bedding plants in the retail setting (Gehring and Lewis, 1979a). The addition of hydophilic polymers (hydrogels) to the growing medium has resulted in bedding plants grown in standard 72 per cell flats that show a 27% delay in wilting (Gehring and Lewis, 1979b). Not all production practices, however, have been effective in increasing the postproduction performance of bedding plants. The use of antitranspirants did not result in prolonged shelf life for any of the bedding plants studied by Gehring and Lewis (1979c).

## Plant Mechanisms for Maintaining Adequate Internal Water Relations

Many people have classified plants according to their mechanisms for dealing with lack

of water. Perhaps the most useful classification for floriculturists is that proposed by Kramer (1983). Kramer has classified plants into drought escapers, syn. avoiders, and drought tolerators. Drought escapers complete their life cycle before serious plant water deficit develops. Kramer divides drought tolerators into two groups - plants that postpone dehydration and those that increase their tolerance to dehydration. Plants that postpone dehydration do so by maintaining a high water potential in spite of an external water stress, primarily by reducing transpiration rates. Plants can accomplish this by dropping leaves, reducing leaf area, developing thicker cuticles, rolling leaves, closing stomata and/or growing a greater (usually deeper) root system (Levitt, 1980). Some plants can also partially acclimate to drought situations by adjusting their internal water relations osmotically so as to maintain turgor. Osmotic adjustment could be advantageous in situations of highly variable rainfall by enabling root expansion into new water sources to continue between rainfalls. Stomatal response may be more successful where crop growth depends on stored water from seasonal rainfall followed by longer periods of drought. Most agricultural researchers working with water stress will classify plants as one of the above described drought tolerators. Thus, they approach their water relations research primarily from either a stomatal or an osmotic adjustment venue.

Bedding plants, specifically Catharanthus, may benefit from both mechanisms of tolerating drought. One mechanism may actually be more beneficial than the other depending on whether the plants are in a retail or a landscape setting. In retail settings, it would be more beneficial for bedding plants to postpone dehydration because of no new media available to explore for additional water resources. In landscape settings it would

be better for the plants to acclimate to dehydration, thus allowing stomata to be at least partially open for carbon gain that would be useful for establishment.

## Morphology and Anatomy and Plant Water Relations

Morphological and anatomical characteristics of plants have a great influence on their drought resistance/tolerance. The structural characteristics that are associated with the ability of a plant to survive under dry conditions are referred to as xeromorphic characteristics. These characteristics include reduced transpirational area, thickened leaves and epidermis, decreased cell size and intercellular spaces, increased vascular tissue area and enhanced root:shoot ratio (Oppenheimer, 1960).

On the whole plant level, it has been well documented that the root:shoot ratio of perennial plants increases as water becomes limiting (Baser et al., 1981; Chung and Trlica, 1980; Davidson, 1969b; Evenari et al., 1977; Finn and Brun, 1980; Nash and Graves, 1993; Schwintzer and Lancene, 1983; Troughton, 1960). The increase in root growth is caused by a shift in the partitioning of dry matter more towards roots rather than shoots (Lambers, 1983). Abscisic acid synthesis induced by water stress has been correlated with this shift in growth pattern (Creelman et al., 1990). Roots have been found to maintain turgor pressure more effectively under water stress than shoots (Schildwacht, 1988). Westgate and Boyer (1985) previously stated that the maintenance of water potential gradients in roots due to differential solute accumulation enabled water to continue to be supplied to enlarging cells. This maintenance of increased turgor pressure and water potential gradients in roots could explain the shift in dry matter accumulation from shoots

to roots. Even though dry matter accumulation usually shifts from shoots to roots during water stress, both shoot and root biomass are usually less than for plants that have not experienced water stress. However, VanDerZanden (1994) reported that for Fragaria chiloensis water stress significantly reduced above ground dry matter production but root dry matter production was not affected. Total dry matter production was reduced between 26% and 35%, depending on the clone, for drought stressed Fragaria plants compared to controls. A higher root:shoot ratio could aid in the establishment of bedding plants into the landscape.

One undesirable effect of water stress at the whole plant level that should be noted is the potential for a delay in flowering time. Panicle emergence in Oryza was found to be delayed by 10 days when plants were grown under water stress conditions (Turner et al., 1986a).

At the leaf level, irradiance levels during growth stages can cause significant changes in a plant's morphology and anatomy, influencing the future drought resistance/ tolerance. It has been documented that plants grown under higher irradiances develop leaves that are very different morphologically than the same plants grown under lower irradiances (Givnish, 1988). Many plant species grown in full sun have been found to produce smaller and thicker leaves than when grown under reduced light levels (Boardman, 1977; Conover and Poole, 1975; Conover et al., 1982; Fails et al., 1982a, 1982b; Johnson et al., 1982a; McClendon and McMillen, 1982; Milks et al., 1979; Mott and Michaelson, 1991; Vidal et al., 1990). Sims and Pearcy (1992) found that the leaves of Alocasia grown in full sun were 41% thicker with a 52% greater mesophyll thickness than plants grown under 20%

shade. This increase in leaf thickness was due to an increase in both cell size and number. Even though the individual leaves of plant species grown under lower light levels are larger (Knecht and O'Leary, 1972). Vidal et al. (1990) reported that the leaf area per plant was less for shade-grown Fatsia than for sun-grown plants. Niklas and Owens (1989) found a similar result with Plantago. Plants growing in shaded environments typically have smaller root systems, longer shoot internodes, an increase in the ratio of petiole length to lamina width and an increase in leaf area per unit dry weight (Doley, 1978; Nobel, 1986; Wilson and Cooper, 1969). Lower leaf masses/area, larger stomata, lesser stomata densities, lower palisade/spongy mesophyll ratios and lower mesophyll cell surface/leaf area ratios have also been reported for plants growing under lower light conditions (Conover and McConnell, 1981; Cormack and Gorham, 1953; Fails et al., 1982a; Givnish, 1988; Johnson et al., 1982b; Lee et al., 1988; Sims and Pearcy, 1992; Vidal et al., 1990).

Moisture availability during stages of active growth can also cause significant changes in a plant's morphology and anatomy, influencing the future drought resistance/tolerance of that plant. Plants growing under conditions of water deficits usually have reduced leaf areas (Bebb and Turner, 1976; Boyer, 1970; Connor and Palta, 1981; Hsiao, 1973; Pearson, 1980). In addition to reduced leaf areas, Vigna grown under increasing levels of drought were found to have lower shoot dry weight, number of leaflets and reduced leaflet area (Turk and Hall, 1980). In a similar study of Phaseolus, water- stressed plants were found to have a higher specific leaf weight (Bonanno and Mack, 1983). The authors attributed this increase in leaf weight to more cell wall material per unit area and/or an

increase in solute and/or starch accumulation in the cells. The number of cells in the leaves of plants subjected to water stress, however, is usually the same as nonstressed controls (Brouwer, 1963). Water stress has also been shown to produce thicker cuticles on plant leaves (Treshow, 1970). In a study of four species of Brassica, there was an increase of epicuticular wax deposits as drought intensity during production increased (Ashraf and Mehmood, 1990). Greater amounts of epicuticular wax have been shown to be associated with adaptation to dry habitats of Medicago (Galeano et al, 1986) and in Trifolium repens and T. incarnatum (Moseley, 1983). The wax content of the cuticle can be more important than the thickness of the cuticle in reducing water loss from leaves (Kramer, 1983).

The light and moisture levels under which a plant is grown can also affect stomatal characteristics. For example, Mott and Michaelson (1991) showed that Ambrosia leaves produced at high light intensities were amphistomatous (stomata occur on abaxial and adaxial surfaces), while those produced at low light intensities were hypostomatous (stomata occur on abaxial surface only). Stomatal density has been shown to decrease for plants grown under low vs. high light levels due to an increase in leaf area (Gay and Hurd, 1975; Wang and Clark, 1992b; Wild and Wolf, 1980). However, Kubinova (1991) found no significant difference in foliar stomatal frequency of Hordeum exposed to differing light conditions. Mott and Michaelson (1991) showed that stomatal density increased on the upper surface of Ambrosia leaves but decreased on the lower surface with increasing light intensity. Stomatal density was found to increase with increasing water stress on both leaf surfaces of Glycine due to a decrease in leaf area (Ciha and Brun, 1975). Wang and Clark

(1992a) reported similar results with Triticum. A greater stomatal density because of water stress was found to be accompanied by a reduction in stomata pore size in leaves of Cassava (Connor and Palta, 1981). Even though stomatal density changes with leaf area, the total number of stomata per leaf has been found to remain fairly constant (Ciha and Brun, 1975; Knecht and O'Leary, 1972). In addition, absolute stomatal density and distribution have been reported to vary among species and cultivars (Willmer, 1983). Stomatal density has been proposed as an indicator of transpiration in plants. However, no significant correlation was found in Antirrhinum between daily transpiration and stomatal density (Rutland et al, 1987). In the same study, daily transpiration was found to be significantly correlated with leaf area as well as total number of stomata per plant, as determined from stomatal frequencies and leaf areas. A similar correlation between water loss and total stomata per leaf was found in Coleus, Epipremnum, Peperomia, Chrysanthemum and Ficus (Rajapakse et al., 1988). Water-use efficiency, however, has been positively correlated with stomatal density (Shearman and Beard, 1973). Another factor to consider when looking at transpiration is diffusive resistance or its inverse, stomatal conductance. Stomatal conductance is a function of the number (frequency), size and degree of opening of stomata (Lugg and Sinclair, 1979; Pospisilova and Solarova, 1980). When soil water is adequate, stomatal aperture is the main determinant of stomatal conductance because it is extremely variable under the influence of atmospheric factors (Burrows and Milthorpe, 1976). When water stress develops and stomata close, differences in stomatal frequency and size may become more important in transpiration (Wang and Clark, 1993a). Stomatal conductance has been reported to be higher for

leaves produced under sun versus shade (Boardman, 1977; Bjorkman, 1981; Mott and Michaelson, 1991).

At the cellular level, water stress is known to have many effects. Water availability can cause anatomical variation of mesophyll cells to occur during leaf development (Kramer, 1983). This variation can be found in the number of mesophyll cells and/or in the cell dimensions themselves. Cells of drought hardened leaves of Brassica were found to be more angular compared to the rounder cells of nonstressed leaves (McBurney, 1992). Water stress has also been reported to produce smaller mesophyll cells, less extensive intercellular spaces, thicker cuticles and increased lignification (Treshow, 1970). McConnell and Host (1980) exhibited both cross and peridermal sections of water-stressed Pereskia, lemon vine, that showed a reduction in mesophyll intercellular spaces and an increase in the number of palisade layers. Leaves of plants watered every 14 days had more strongly differentiated palisade layers with more cells than the leaves of plants watered every 7 days (McConnell and Host, 1983). Such anatomical changes have been shown to increase water-use efficiency in other plants (Nobel, 1980). Changes in mesophyll cell anatomy result in varying amounts of internal leaf area available for carbon dioxide absorption per unit leaf surface area, which can affect both photosynthesis and water use efficiency. An increase in mesophyll surface area per unit leaf area ($A^{mes}/A$) should yield higher photosynthetic rates and higher water use efficiencies. Triticum with smaller mesophyll cells and a greater $A^{mes}/A$ had a greater photosynthetic capacity than winter wheat with larger mesophyll cells (LeCain et al., 1989). In a study of Salix, maximum net photosynthesis rates were found to be correlated with greater $A^{mes}/A$

(Patton and Jones, 1989). $A^{mes}/A$ was found to increase 50% at the same leaf thickness for water stressed Encelia farinosa compared to well-watered plants (Cutler et al., 1977). The water stressed plants were also found to have smaller mesophyll cells. Smaller cells should maintain turgor to lower water potential values due to a greater percentage of bound water. In a similar study, $A^{mes}/A$ increased approximately 40% in leaves of Plectranthus parviflorus when soil water potential was decreased from 0 to -10 bars (Nobel, 1977). Similar results have been shown to occur with high versus low light conditions. Kubinova (1991) found that leaves of Hordeum were thicker and had a higher $A^{mes}/A$ when grown under higher irradiances. Other plant species have been found to respond similarly (Chabot and Chabot, 1977; Longstreth et al, 1985; Nobel et al., 1975). It should be noted that changes in mesophyll anatomy do not always result in a change in photosynthetic capacity and/or efficiency as reported by Foote (1994) with Fragaria.

Plant cell walls are flexible structures that can change in response to a changing environment (Fincher and Stone, 1981). The flexibility of plant cell walls is expressed as the modulus of elasticity (E). Cells with rigid walls have a higher E than cells with more flexible walls. It has been reported that the cell walls of most plants become more elastic with decreasing turgor potential (Colombo, 1987; Roberts et al., 1981; Tyree and Jarvis, 1982). Cell wall elasticity is an important factor in turgor maintenance. Knapp (1984) argued that plants with more elastic walls (lower E) will have a lower water potential at zero turgor. In other words, the plants will maintain turgor longer as water potential declines. On the other hand, cells with rigid walls undergo a smaller decrease in volume and water content for a given decrease in water potential than do cells with elastic cell

walls (Kramer, 1983). Bowman and Roberts (1985) suggested that more rigid cell walls (higher E) would have a lower water potential for a given change in water volume which would maintain a steeper water potential gradient that would facilitate the continued uptake of water from drying soils. Either a decrease or an increase in cell wall elasticity could benefit plants during water stress, depending on various factors including stress intensity and duration and the plant's physiological status and survival strategy. For example, cells with rigid walls lose turgor rapidly with water loss which is a mechanism that may be important for stomatal closure or leaf rolling and folding in some grasses. Melkonian et al. (1982) found in Triticum that three cycles of water deficits decreased cell wall elasticity. Conversely, Barker et al. (1993) reported that for the $C_3$ grasses studied more flexible cell walls were the result of exposure to water stress. Similarly, preconditioning of Picea mariana with osmotic stress was shown to help the seedlings maintain turgor during subsequent exposure to water stress (Zwiazek and Blake, 1989). This turgor maintenance was later shown to be due to an accumulation of soluble sugars and an increased cell wall elasticity (Blake et al., 1991).

## Growth Retardants and Plant Water Relations

Plants treated with growth retardants have shown increased resistance to environmental stresses, including drought (Barrett and Nell, 1982; Cathey, 1964; Morandi et al., 1984). Treated Pinus elliottii (Asher, 1963), Lycopersicum (Mishra and Pradhan, 1968; Pill et al., 1979) and Phaseolus (Plaut et al., 1964) lost less water due to reductions in transpiration. Growth retardants affect transpiration by either increasing stomatal

resistance to diffusion and/or by effecting changes in leaf morphology (Atkinson and Chauhan, 1987; Barrett and Nell, 1981; Barrett and Nell, 1982). The primary change in leaf morphology is a reduction in leaf area due to a gibberellin inhibition. It was found that Lycopersicum treated with chlormequat had reduced transpiration because of reduced stomatal aperture (Mishra and Pradhan, 1968). Stomata of treated plants were closed by 80% one day after treatment, 30-40% after six days and 20% after 14 days. In a later study, the wilting of Lycopersicum plants treated with cycocel or daminozide was delayed 4 days as compared to control plants when water was withheld 59 days after the final applications of growth retardants (Mishra and Pradhan, 1972). Three weeks after treatment, Euphorbia pulcherrima drenched with chlormequat or ancymidol had reduced whole plant transpiration by 12 and 24%, respectively (Barrett and Nell, 1981). In another poinsettia study, total evapotranspiration was reduced by 20% in ancymidol treated plants compared to controls (Barrett and Nell, 1982). The retardants did not alter the plants' transpiration rate as measured by water loss per unit leaf area or unit shoot dry weight. Rather, the reduced water loss was due to reductions in leaf area. Similar results have been reported for Chrysanthemum (Bryan, 1989) and Helianthus (Wample and Culver, 1983). However, Asamoah and Atkinson (1985) found that Prunus rootstocks treated with paclobutrazol exhibited reduced water loss on both a total plant as well as on a unit leaf area basis. Total water use and transpiration were also reduced on Malus and Prunus rootstocks treated with paclobutrazol (Atkinson and Chauhan, 1987). The reduced transpiration was found to be due to increased stomatal resistance as well as from a reduction in leaf area. Hibiscus drenched with uniconazole showed a 33% reduction in

water used compared to controls (Steinberg et al., 1991). Chemically treated plants had a smaller leaf area and individual leaves had a lower stomatal density, conductance and transpiration rate than control plants.

The application of chemical growth retardants can produce other effects besides changes in stomatal behavior and reductions in leaf area. Growth retardants can produce positive changes such as decreased plant height by shortening internodes (Andrasek, 1989; Barrett and Nell, 1989; Barrett and Nell, 1992; Bryan, 1989; Davis et al., 1987), increased number of flowers per plant (Andrasek, 1989), hastened flowering (Andrasek, 1989), darkened foliage color by concentrating chlorophyll (Andrasek, 1989; Bryan, 1989) and a greater root:shoot ratio (McConnell and Struckmeyer, 1970). On the other hand, growth retardants can produce negative changes such as reduced flower size (Andrasek, 1989), slow landscape establishment (Latimer, 1991) and potential plant distortions. These studies show that growth retardants not only can aid in the production of a more compact and salable bedding plant, but can also be used to produce plants that are better able to tolerate periods of suboptimum water supplies that may be experienced after leaving the greenhouse environment.

## Moisture Stress Conditioning and Plant Water Relations

Moisture stress conditioning refers to the intentional exposing of plants to one or more wilt cycles during their production period in an attempt to acclimate them to future water deficits. Much research has been undertaken that shows many plants undergo osmotic adjustment during periods of water deficits (Ackerson and Hebert, 1981; Edwards and

Dixon, 1995; Gupta and Berkowitz, 1987; Matthews and Boyer, 1984; Osonubi and Davies, 1978; Premachandra et al., 1992; Seiler, 1985; Seiler and Johnson, 1988). In higher plants, osmotic adjustment refers to the lowering of osmotic potential due to the net (active) accumulation of solutes (Jones and Turner, 1980). The solutes that accumulate during osmotic adjustment include sugars, amino acids, organic acids, alkaloids, proline and glycine betaine (Hanson and Hitz, 1982). Osmotic adjustment in response to water deficits can either fully or partially maintain plant turgor. Turgor maintenance for a plant under water stress can allow for continued photosynthesis and plant growth by helping to keep stomata at least partially open, allowing for carbon dioxide to reach the chloroplasts. A higher degree of osmotic adjustment does not always result in increased stomatal opening. Premachandra et al. (1992) found that the Zea cultivars with a higher degree of osmotic adjustment did not maintain higher stomatal conductance than the cultivars with a lower degree of osmotic adjustment. However, Hordeum genotypes with higher levels of induced osmotic adjustment by drought stress showed decreased reductions in growth compared to genotypes that underwent less osmotic adjustment (Blum, 1989). In a study of the response of four Brassica species to drought stress, B. napus had both the greatest osmotic adjustment and shoot fresh weight (Ashraf and Mehmood, 1990). Osmotic adjustment in Condor wheat allowed for the maintenance of a greater chloroplast volume at low water potentials, which resulted in greater photosynthetic rates (Gupta and Berkowitz, 1987). Sorghum plants exposed to water stress over a period of 15 days osmotically adjusted and had a higher net daily carbon gain per unit of gross carbon input when compared to plants that were irrigated

daily (McCree, 1986). In fact, the water-stressed Sorghum plants continued to gain carbon throughout the stress cycle. Rodriguez-Maribona et al. (1992) showed that a positive linear relationship existed between yield and osmotic adjustment in Pisum grown under drought stress. In a later study with Vigna and Beta, it was concluded that both osmotic adjustment and stomatal control of water loss were necessary to be able to lengthen the irrigation cycle so as to maximize water savings (McCree and Richardson, 1987).

Melkonian and Wolf (1995) discovered that it required a minimum of two water stress cycles before Cucumis exhibited osmotic adjustment. However, Edwards and Dixon (1995) showed that just one drought episode was able to initiate osmotic adjustment in Thuja occidentalis. Turner et al. (1986b) discovered for Oryza cultivars that the degree of osmotic adjustment was correlated with the cumulative stress days above a threshold cumulative leaf water potential of -16 to -17 MPa days. In addition to moisture-stress-conditioning lowering a plant's osmotic potential at full turgor and water potential at zero turgor, this conditioning may also result in a higher bound water content and dry weight/turgid weight ratio, which also would assist the plant in maintaining growth under future water stress periods (Clayton-Greene, 1983). Finally, in Helianthus, moisture stress conditioning resulted in the acclimation of photosynthesis to lower water potentials by both stomatal and chloroplast acclimation (Matthews and Boyer, 1984). It should be noted that genotypic differences often exist within a plant species that affect the occurrence and degree of osmotic adjustment (Ackerson, 1980, Johnson et al., 1987; Mojayad and Planchon, 1994; Seropian and Planchon, 1984; Sobrado and Turner, 1983;

Tan et al., 1992; Virk and Singh, 1990). Bennett et al. (1981), however, did not find any significant differences in the leaf water potential at which zero turgor potential occured among the genotypes of peanut studied.

In addition to moisture stress conditioning affecting osmotic adjustment, it can influence stomatal behavior, in particular stomatal resistance/conductance. Stomata operate to meet two often conflicting requirements: (a) maximizing carbon dioxide assimilation and (b) preventing the reduction of plant water status to substantially damaging levels (Bradford and Hsiao, 1982). Stomatal conductance is affected by relative humidity, carbon dioxide concentrations, light and soil moisture. Many studies have shown that stomatal closure can be induced by soil drying before there is any measurable change in the total water potential or turgor potential of the shoots (Bates and Hall, 1981, 1982; Blackman and Davies, 1985; Davies et al., 1980; Gollan et al., 1986; Gowing et al., 1990; Kuppers et al., 1988; Passioura, 1980; Saab and Sharp, 1989; Zhang and Davies, 1989, 1990a; Zhang and Davies, 1987). It has been proposed that roots sense soil drying and produce chemical signals which can move through the transpirational stream to affect processes in the shoots that lead to stomatal closure. Specifically, increased ABA concentration in the apoplast surrounding the guard cells makes more ABA available to ABA receptors present on the outer surface of the plasmalemma of the guard cells (Hartung and Davies, 1991). In Zea and Helianthus, soil drying was found to increase the synthesis of abscisic acid (ABA) by the roots which then moved into the shoots via the transpirational stream and inhibited stomatal opening and leaf growth (Zhang and Davies, 1987; Zhang and Davies, 1989, 1990a). A study with Phaseolus, which has higher

concentrations of ABA than Zea and Helianthus even under well watered conditions. suggested that the control of stomata occurs by the redistribution of existing ABA (Trejo and Davies, 1991). Evidence that moisture stress conditioning can affect either osmotic adjustment or stomatal resistance or both, depending on the species, has been reported from recent work done with Thuja occidentalis (Edwards and Dixon, 1995). An earlier study of Pereskia showed that the transpiration rates of previously water-stressed plants were found to be lower than in unstressed plants, showing an effect on stomatal resistance (Kaufmann and Levy, 1976). Another factor that can affect stomatal conductance is leaf age. Jordan et al. (1975) found that the younger leaves of Gossypium kept their stomata open to lower water potentials than older leaves. The recovery of stomatal aperture lags behind the rehydration of a plant following a stress period. This lag of stomatal recovery has been attributed to a persistent effect of abscisic acid produced during the stress period (Bengtsson et al., 1977; Fischer et al., 1970). Rapid recovery of stomatal aperture when water is once again available would be advantageous in increasing carbon assimilation rates, although a more rapid depletion of the new water reserves in the soil would also occur. Once again, genetics can play a substantial role in how stomata respond to drought. For example, Nicotiana tabacum, usually grown under adequate water supplies, responded to drought by reducing leaf area but not leaf conductance (Pearson, 1980). N. rustica, normally grown with a limited water supply, responded to drought by reducing both leaf area and leaf conductance, which resulted in a much greater decrease in canopy conductance.

Other research has been conducted to evaluate the influence of the rate of water stress development on net photosynthesis, leaf conductance and leaf turgor potential. Sorghum that experienced slower rates of water deficits had more osmotic adjustment than plants that experienced rapid water deficits (Jones and Rawson, 1979). Plants that experienced the more rapid developing water deficits also had lower net photosynthesis and reduced water-use efficiencies. In the same study, the authors also found that prior water stresses most helped the plants during subsequent water stresses when the time between recovery from stress and the onset of the next drying cycle was less than one week, and when leaf water potentials dropped rapidly during the subsequent stress period. Jones et al. (1985) also reported that with fruit trees a rapid development of water stress may impede osmotic adjustment. Thomas et al. (1976) conducted an experiment to determine if field-grown Gossypium exhibited similar stomatal behavior to Gossypium and other plants grown in containers under greenhouse conditions. It stands to reason that field-grown plants would require a longer period of time to develop comparable stress to plants grown in the limited rooting volume of a container. Thomas showed that the stomata of field-grown cotton subjected to water stress remained open to lower leaf water potentials than the control plants. This change in stomatal response in the field occurred without the plants showing visible signs of wilting. These results were similar to those found previously on chamber-grown plants that had experienced more frequent but shorter water stress periods (Brown et al, 1976). Sobrado and Turner (1983) found that the osmotic adjustment of field-grown Helianthus was considerably smaller than the maximum degree of osmotic

adjustment observed at more severe levels of stress imposed in the greenhouse by other researchers (Jones and Turner, 1980; Takami et al., 1981, 1982).

Moisture stress conditioning research has also been conducted with bedding plants. Photosynthesis in hybrid Pelargonium was found to decline at a slower rate as soil moisture levels dropped if the plants were previously exposed to a single moisture stress cycle (Armitage et al., 1983). Salvia plants that had been exposed to four nonlethal dry-down cycles prior to measurements being taken showed a 30% reduction in evapotranspiration per unit leaf area and a 32% reduction on a per plant basis when compared with control plants (Eakes et al., 1991a). The leaf turgor potential was also higher at any given leaf water potential for moisture-stress-conditioned plants. The water-stressed plants were able to maintain higher turgor potentials due to osmotic adjustment. In another study, moisture-stress-conditioned Salvia maintained greater photosynthetic rates during day 2 of a wilt due to reductions in water loss during day 1 and due to the plants' ability to maintain photosynthesis at a lower leaf water potential (Eakes et al., 1991b). The authors also reported that the moisture stress conditioned plants had higher water-use efficiencies than control plants. Catharanthus has also been shown to osmotically adjust in response to the slow and gradual development of moisture stress (Virk and Singh, 1990). It was found that the polar water soluble alkaloids were the main contributors of osmotic adjustment in periwinkle. The cultivar of periwinkle studied that had the greatest drought tolerance also was found to have a higher level of bound water and cell wall extensibility compared to the other less drought-tolerant cultivars.

Research has also been conducted to determine the effects of water stress on subsequent plant growth. Ficus benjamina exhibited reduced growth during three short-term water rationing treatments (Fitzpatrick, 1983). However, the plants then showed accelerated growth after the water rationing ceased. This recovery phenomenon was not found in the other two plant species studied, Philodendron selloum and Brassaia actinophylla. Both of these species showed reduced growth for more than two months after termination of short-term water rationing. Hall (1993) reported that Medicago plants subjected to drought stress produced a greater leaf area than the controls upon release from the drought stress. The same study found that stem length and dry matter yield was reduced in stressed plants during periods after water stress was removed.

## Nitrogen Supply and Plant Water Relations

Fertilization has a tremendous impact on plant growth. Nitrogen, in particular, has been reported by several investigators to interact with water to affect plant yields (Barker et al., 1983; Crowther, 1934; Hearn, 1975). The effects of nitrogen and water supply on stomatal behavior has been shown to be variable between plant species and between greenhouse and field studies. It has been reported that suboptimal nitrogen increases stomatal closure of Gossypium in response to water stress (Radin and Ackerson, 1981; Radin et al., 1982). This stomatal closure has been attributed to a greater accumulation of abscisic acid in stressed leaves as well as a greater stomatal response to abscisic acid. Similar effects of nitrogen on stomatal behavior has been seen in Camellia (Nagarajah, 1981), Zea (Bennett et al., 1986) and Panicum (Ludlow and Ng, 1976) grown

under controlled environments but not in Triticum (Morgan, 1986), Coffea (Tesha and Kumar, 1978), Avena (Zwicker, 1965), Phaseolus (Shimshi, 1970a), Panicum grown outdoors (Ludlow, 1976) and Gossypium grown outdoors (Radin et al., 1991). Radin et al. (1985) found that the stomata of irrigated Gossypium fertilized with high nitrogen remained open to water potentials that were below the wilting point during the early part of the growing season. However, the stomata of low nitrogen plants closed at water potentials closely associated with the wilting point throughout the season. Ultimately, the effects of low nitrogen on plant water relations and water use were such that 10-cm irrigations produced as much yield and a higher water-use efficiency than 15 cm irrigations. The greater drought tolerance of low nitrogen Triticum plants in Morgan's study (1986) was related to changes in internal water relation traits, particularly an increase in cell wall rigidity that resulted in a greater retention of water at lowered water potentials, rather than increased stomatal sensitivity. Shimshi (1970b) found that nitrogen-deficient Phaseolus failed to open their stomata as widely and to close them as tightly as nitrogen-supplied plants. When soil moisture was high, the transpiration rates of nitrogen-supplied plants were higher than those of nitrogen-deficient plants. As soil moisture decreased to levels that caused plant wilt, the transpiration rates of nitrogen-supplied plants dropped below those of nitrogen-deficient plants. He concluded that nitrogen deficiency impairs the ability of the plants to adjust their water status to changes in soil moisture stress by regulation of stomatal transpiration and of sap-solute concentration. Bennett et al. (1986) found that field-grown Zea given high nitrogen was less affected by water stress than low-nitrogen plants. They observed that high-nitrogen plants were able

to maintain leaf turgor, open stomata and higher rates of individual leaf transpiration despite similar reductions in leaf water potentials between high and low-nitrogen plants during periods of low soil water availability. Bennett also proposed that the lower osmotic potential of high-nitrogen plants could have contributed to the extraction of more water from the soil profile. Similar reductions in osmotic potential at lower leaf water potentials for high-nitrogen plants were found in Helianthus leaves (Radin and Boyer, 1982) and Raphanus sativus leaves (Hegde, 1987) but not in Gossypium leaves (Radin and Parker, 1979). Johnston and Fowler (1992) discovered that nitrogen fertilization affected the leaf conductance of wheat differently depending upon the plants' physiological stage of development. Increased nitrogen levels resulted in increased pre-anthesis leaf conductances and decreased post-anthesis conductances. The differences found in how nitrogen and water stress interact to affect the water relations in the crops reported here may be due to their respective mechanisms for tolerating drought, ie. osmotic adjustment versus water conservation strategies such as stomatal closure.

## Summary

The manner in which a floriculture crop is produced has measurable effects on its postproduction performance. These effects can be attributed to both anatomical and physiological changes that develop during production of the crop. Any production practice that would enable bedding plants to conserve moisture at a retail setting and aid establishment in the landscape, without increasing production costs, would be extremely desirable. Many bedding plants are routinely produced with some type of growth-

regulator application. In addition to reducing plant size, these chemicals can also reduce transpiration rates by reducing leaf area and/or increasing stomatal resistance. The use of chemical growth regulators can thus improve the performance of bedding plants in a retail setting, but evidence exists that such growth regulators can also slow landscape establishment (Latimer, 1991). Moisture stress conditioning, commonly used to reduce plant growth before the widespread availability of chemical growth regulators, is being investigated recently as an alternative to chemicals. Moisture stress conditioning during production has been found to promote osmotic adjusment in bedding plants (Eakes, et al., 1991b; Virk and Singh, 1990). Osmotic adjustment could allow for turgor to be maintained at lower water potentials, keeping stomata at least partially open for carbon assimilation which would be advantageous for landscape establishment under conditions of less than ideal moisture. The effect of moisture stress conditioning on stomatal resistance is still unclear. Thus, moisture stress conditioning may or may not improve the performance of bedding plants in a retail setting, where increased stomatal resistance would be an advantage. An extremely limited amount of research has been done on bedding plants that compares the use of chemical growth regulators and moisture stress conditioning during production on postproduction performance. How nitrogen fertilization and moisture stress conditioning during production affect postproduction performance of bedding plants is also an area that has received very little research attention. Finally, the relationships that have been reported between production factors and postproduction performance of bedding plants have not been explained at an anatomical or physiological level.

# CHAPTER 3
# DIURNAL FLUCTUATIONS OF STOMATAL CONDUCTANCE, TRANSPIRATION, XYLEM WATER POTENTIAL AND PHOTOSYNTHESIS IN CATHARANTHUS ROSEUS

## Introduction

A preliminary investigation was undertaken to determine the diurnal fluctuations of stomatal conductance, transpiration, xylem water potential and photosynthesis in Catharanthus roseus 'Cooler Peppermint'. The goal of this investigation was to determine the most appropriate time during the day for taking physiological measurements for evaluating water stress in subsequent studies. Diurnal xylem pressure potential curves exist for a variety of woody angiosperms and various crop species (Richie and Hinckley, 1975). However, the exact diurnal behavior of Catharanthus roseus was not known before the initiation of these studies.

## Materials and Methods

Seedlings of Catharanthus roseus 'Cooler Peppermint' grown in 390 plug trays were shipped from Natural Beauty in Apopka, Florida, to Gainesville, Florida on 10 Mar. 1994. The 18 x 18 mm plugs were transplanted into 10 cm diameter by 8 cm deep plastic containers using Vegro Clay Mix (Verlite Co, Tampa, Florida) medium on 11 Mar. All plants were thoroughly watered and spaced on wire mesh benches in a Lexan-covered

greenhouse. Since some plugs contained multiple plants, all but one plant per container were basally cut with a pair of scissors. Plants were maintained well watered as necessary throughout the experiment and the plants never experienced wilting conditions. Liquid fertilizer derived from 20% N, 4.3% P, 16.6% K was applied at a concentration of 150 ppm N during each watering. All plants were thoroughly watered at 2100 hours on the day before diurnal measurements were taken.

Beginning at 0600 hours and continuing until 2000 hours on 30 April 1994, measurements were taken every 2 hours on five plants. Average greenhouse irradiance and vapor pressure for each 2-hour time interval were recorded (Figure 3-1). Photosynthesis was determined with a portable photosynthesis system (Li-Cor, Inc. Model LI-6200) with a flow rate of 945 mol $m^{-3}$ and a leaf area of 24 mm x 36 mm. Measurements were taken from the youngest, fully expanded leaf. Leaf abaxial water vapor conductance, transpiration, light, relative humidity, leaf temperature and air temperature were determined with a steady state porometer (Li-Cor, Inc. Model Li-1600), using a 2-$cm^2$ aperature and an average atmospheric pressure of 104 KPa. Measurements were taken from the same leaf as the photosynthesis readings.

Xylem water potential was determined with a Scholander (1965) pressure chamber (PMS Instrument Co., Model 600). Six- to eight-cm stem tip cuttings were removed from each plant and the two lower leaves were removed at the petiole base with a sharp razor blade and then the cutting was immediately placed in a small plastic bag containing a moist paper towel to inhibit desiccation during measurements (Barrett and Nell, 1983). Pressure was increased at a rate of 0.6 MPa per minute until a drop of moisture was seen

exuding from the cut portion of the stem, at which time the xylem water potential reading was taken.

Stomatal conductance values were calculated as the inverse of the diffusive resistance readings taken from the porometer. Stomatal conductance, transpiration, xylem water potential and photosynthesis values were averaged for each measurement time and standard deviations were calculated.

## Results and Discussion

Stomatal conductance was zero at 0600 hours, a predawn reading, and rose rapidly, reaching its peak value of 743 mmol $m^{-2}$ $s^{-1}$ at 1400 hours (Figure 3-2). Leaf conductance then dropped slightly to 649 mmol $m^{-2}$ $s^{-1}$ at 1600 hours and proceeded to drop rapidly until reaching zero again at 2000 hours. Transpiration followed a similar trend to leaf conductance (Figure 3-2). Transpiration was zero at 0600 hours, rose slightly to 0.812 mmol $m^{-2}$ $s^{-1}$ at 0800 hours and rose rapidly, reaching its peak value of 16.40 mmol $m^{-2}$ $s^{-1}$ at 1400 hours. Transpiration then dropped rapidly until reaching zero again at 2000 hours.

Predawn xylem water potential was -0.24 MPa at 0600 hours, fell slightly to -0.27 MPa at 0800 hours and then fell rapidly to -0.94 MPa at 1400 hours (Figure 3-2). Xylem water potential proceeded to fall very slightly to its lowest value of -0.97 MPa at 1600 hours, at which time it increased to -0.33 MPa by 2000 hours. This diurnal xylem water potential curve is similar to a generalized diurnal xylem pressure potential curve presented

by Richie and Hinkley (1975) and to the curve reported by Pivorunas (1982) for well watered 'Gloria' azalea.

Predawn net carbon gain was -1.55 $\mu$mol $m^{-2}$ $s^{-1}$ at 0600 hours (Figure 3-2). Net photosynthesis at 0800 hours was 3.21 $\mu$mol $m^{-2}$ $s^{-1}$, rose rapidly to its peak value of 26.99 $\mu$mol $m^{-2}$ $s^{-1}$ at 1200 hours, dropped slightly to 24.41 $\mu$mol $m^{-2}$ $s^{-1}$ at 1600 hours and declined rapidly to -0.56 $\mu$mol $m^{-2}$ $s^{-1}$ at 2000 hours. Even though stomatal conductance continued to increase until 1400 hours, photosynthesis reached its peak at 1200 hours, indicating that photosynthesis had reached its saturation point.

Stomatal conductance and transpiration followed very similar diurnal curves (Figure 3-2), indicating that stomatal opening is a good indicator of transpirational water loss in Catharanthus roseus under the environmental conditions present in the greenhouse during this study. This pattern was not observed with well watered `Gloria' azalea where stomata underwent partial closure after maximum opening at 1000 hours without a corresponding decline in transpiration (Pivorunas, 1982). The author attributed the continued high rate of transpiration even after partial stomatal closure to a high vapor pressure deficit.

Stomatal conductance and transpiration both started to decline in Catharanthus from their peak rates at 1400 hours. However, xylem water potential remained constant between 1400 and 1600 hours, at which time it reached its lowest level. In other words, the water lost from the plants was not being regained until two hours after the stomata began to close, which represents a two hour lag. Thus, the best time to measure xylem water potential in well watered Catharanthus roseus `Cooler Peppermint' was found to

occur between 1400 and 1600 hours, when xylem water potential was fairly constant and at its lowest level. This low level represents the period during the day when the plants were experiencing the greatest amount of leaf water deficit.

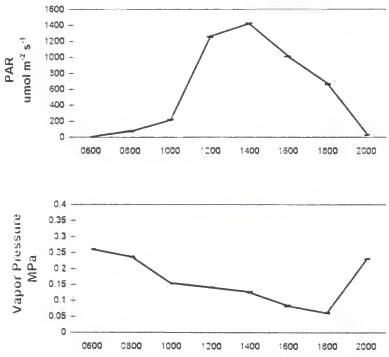


Figure 3-1 Average greenhouse irradiance and vapor pressure for each two hour time interval on 30 Apr. 1994.

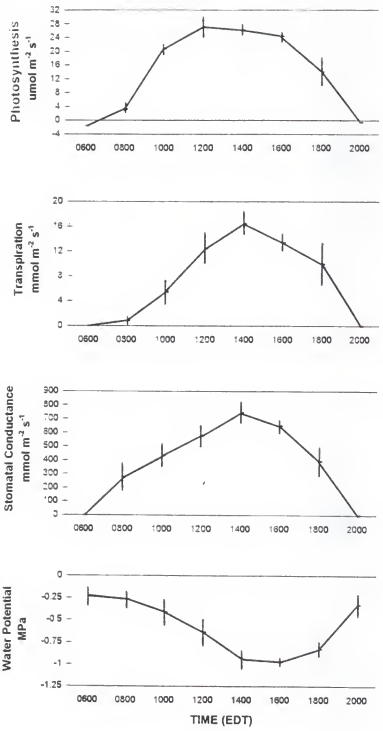


Figure 3-2 Diurnal cycles of photosynthesis, transpiration, stomatal conductance and xylem water potential in well-watered Catharanthus roseus 'Cooler Peppermint' on 30 Apr. 1994.

# CHAPTER 4
# ANATOMICAL AND PHYSIOLOGICAL EFFECTS OF PRODUCTION LIGHT AND WATER REGIMES ON THE GREENHOUSE GROWTH AND LANDSCAPE PERFORMANCE OF CATHARANTHUS ROSEUS 'COOLER PEPPERMINT'

## Introduction

Much research has been done in the areas of crop breeding and environmental conditions during plant production to assist bedding plant growers in efficiently producing an attractive and profitable crop. Bedding plant growers have recently become more aware of the need for improved postproduction performance, both in retail and landscape settings (Armitage, 1986; Hammer, 1988). Armitage (1993) has compiled the latest recommendations for how to modify light, temperature, irrigation and growth regulator applications during plant production for several major species of ornamental bedding plants with the goal of improving postproduction performance. However, very few studies have been performed where anatomical and physiological changes have been investigated to evaluate and explain the effects of the production environment on the postproduction performance of ornamental bedding plants in actual retail and/or landscape settings.

Morphological and anatomical characteristics of plants have a great influence on their drought resistance and/or tolerance. Structural characteristics such as reduced leaf transpirational area, a thickened leaf and epidermis, decreased cell size and intercellular

spaces, increased vascular tissue area and enhanced root:shoot ratio are associated with the ability of a plant to survive under dry conditions (Oppenheimer, 1960). Plants grown under conditions of water deficits were shown to have reduced leaf areas (Bebb and Turner, 1976; Boyer, 1970; Connor and Palta, 1981; Hsiao, 1973; Pearson, 1980). Stomatal density was found to increase with increasing water stress due to a decrease in leaf area (Ciha and Brun, 1975; Wang and Clark, 1992b). Even though stomatal density changes with leaf area, the total number of stomata per leaf has been found to remain fairly constant (Ciha and Brun, 1975; Knecht and O'Leary, 1972). Higher light (Kubinova, 1991) or water stress during growth (Kramer, 1983 can cause mesophyll cells to decrease in both number and/or size. An increase in mesophyll surface area per unit leaf area ($A^{mes}/A$) can result in higher photosynthetic rates and higher water use efficiencies (LeCain et al., 1989; Patton and Jones, 1989). Changes in mesophyll anatomy have not always resulted in changes in photosynthetic capacity and/or efficiency (Foote, 1994). No literature was discovered that reported using anatomical studies to explain the effects of production light and water regimes on the postproduction performance of a bedding plant. Given what is known for other plants, it was expected that producing Catharanthus under higher light and water stress would result in smaller mesophyll cells that would improve the plants' water relations and photosynthetic capacity in the field, allowing for faster establishment and growth.

Ficus benjamina (Conover and Poole, 1975) and Euphorbia pulcherrima (Nell and Barrett, 1986) performed better under interior conditions when grown under lower light levels during the last stages of production. The improvements in interior performance

were attributed to a decrease in light compensation points. Lower leaf dry weight/area, larger stomata, lower stomata densities, lower palisade/spongy mesophyll ratios and lower mesophyll cell surface/leaf area ratios have been reported for other plants growing under lower light conditions (Conover and McConnell, 1981; Cormack and Gorham, 1953; Fails et al., 1982a; Givnish, 1988; Johnson et al., 1982a; Lee et al., 1988; Sims and Pearcy, 1992; Vidal et al, 1990). However, little work has been done to test the effect of reduced production light levels on the postproduction performance of bedding plants in a landscape setting. Because light was not a limiting growth factor for Catharanthus in the field, it was expected that producing plants under lower light levels in the greenhouse would not yield any great advantage in terms of field growth. However, a potential interaction between lower greenhouse light levels and water stress during production on mesophyll cell size was investigated.

Moisture stress conditioning during production was reported to improve the growth and/or yield of several agronomic crops when exposed to future moisture stress periods (Ackerson and Hebert, 1981; Brown et al., 1976; Gupta and Berkowitz, 1987, Matthews and Boyer, 1984). Plants conditioned to moisture stress maintained greater stomatal conductance and levels of photosynthesis during subsequent moist stress conditions when compared to the well-watered controls. Increased photosynthesis in conditioned plants was attributed to positive osmotic adjustment and/or by stomatal and chloroplast acclimation to lower water potentials. Catharanthus roseus was shown to osmotically adjust in response to the slow and gradual development of moisture stress (Virk and Singh, 1990).

Photosynthesis in Pelargonium was found to decline at a slower rate as soil moisture levels dropped if the plants were previously exposed to a single moisture stress cycle (Armitage et al, 1983). Salvia exposed to four nonlethal dry-down cycles showed a 30% reduction in evapotranspiration per unit leaf area and higher leaf turgor potentials at any given leaf water potential over well-watered controls (Eakes et al., 1991a). Conditioned Salvia maintained greater photosynthetic rates in the greenhouse during day 2 of a wilt due to reductions in water loss during day 1. The conditioned plants were also able to maintain photosynthesis at a lower leaf water potential (Eakes et al., 1991b). None of the plants in the above two studies were evaluated in a real-world retail and/or landscape setting to see if the physiological gains from moisture stress conditioning during production actually resulted in any postproduction benefit.

Some evaluations of the postproduction performance of vegetable transplants has been done in field settings. No improvements in the field establishment of Brassica were gained when the plants were subjected to drought stress during production (Latimer, 1990). This water stress, however, was very mild as the plants were only allowed to wilt for 2 to 4 hours before being thoroughly rewatered. Armitage and Kowalski (1983) found that growing Petunia x hyrbida with less frequent irrigation regimes improved postproduction plant quality. No physiological processes were measured that may have assisted in explaining these results. Also, these plants were evaluated in postproduction chambers and did not receive any moisture stress following production.

The objective of this study was to use leaf anatomy and physiological characteristics to evaluate and explain the effects of two production light levels and four production water

regimes on the postproduction performance of Catharanthus in landscape beds.

## Materials and Methods

Experiment 1. This experiment was conducted to investigate the effects of production light levels and water stress on the transpiration per unit leaf area, osmotic adjustment and turgor loss point of Catharanthus roseus 'Cooler Peppermint'.

Seedlings were grown in 390 plug trays were shipped from Natural Beauty Greenhouses in Apopka, Florida, to Gainesville, Florida on 6 June 1996. The 18 x 18 mm plugs were transplanted into 10-cm diameter by 8-cm deep plastic azalea containers using Vegro Clay Mix (Verlite Co., Tampa, Florida) medium on 7 June. All plants were thoroughly watered and spaced on wire mesh benches in a Lexan-covered greenhouse. Since some plugs contained multiple plants, all but one plant per container were basally cut with a pair of scissors. Plants were maintained well-watered as necessary and never experienced wilting conditions during the subsequent 2-week period.

On 21 June, all plants were placed into a randomized, complete block design with five plants per experimental unit and three replications. The experiment was 2 x 4 factorial with 2 light levels and 4 water stress regimes. The two light regimes were "high" (full greenhouse irradiance levels which averaged 1,550 $\mu$mol $m^{-2}$ $s^{-1}$ at midday) and "low" (67% of full greenhouse irradiance levels which averaged 1,025 $\mu$mol $m^{-2}$ $s^{-1}$ at midday). The four watering regimes were "WW" (plants were maintained well watered throughout the entire experiment), "LW+1" (plants were maintained well watered until the last two weeks of the experiment during which time they were allowed to wilt for one day between

waterings), "W+1" (plants were allowed to wilt for one day between waterings throughout the production period for a total of seven dry down cycles), "W+3" (plants were allowed to wilt for three days before between waterings throughout the production period for a total of six dry down cycles). Liquid fertilizer derived from 20% N, 4.3% P, 16.6% K was applied at a concentration of 150 ppm N during each watering throughout the experiment.

To determine transpiration per unit leaf area all plants were thoroughly watered at 0700 hours on 29 July and excess water was allowed to drain. At 0900 hours, each container was enclosed in a plastic bag and weighed at 0900, 1300, 1700 and 2100 hours. The following day, total leaf area was determined for each plant using a portable leaf area machine (Li-Cor, Inc. Model Li-3000A). Transpiration per unit leaf area (mmol $m^{-2}$ $s^{-1}$) was calculated for each time interval and data were subjected to analysis of variance and Tukey mean separation.

To construct pressure-volume (PV) curves, 10 plants were randomly selected from each of the high light x water treatments during the week of 1 Aug. Due to the time required to obtain reliable data, the only low light x water treatment selected for study was the W+1 treatment. This water treatment was selected to compare the effects of high versus low production light because of preliminary research that showed the landscape benefits of the W+1 water treatment. Plants were placed in a dark room and well watered the evening before pressure-volume measurements were to occur to ensure full turgor. Xylem water potential was measured with a Scholander pressure chamber (PMS Instrument Co., Model 600). One six- to eight-cm stem tip cutting was removed from

each plant. The two lower leaves were removed at the petiole base with a sharp razor blade, and the cutting was immediately placed in a small plastic bag containing a moist paper towel to inhibit desiccation during measurements (Barrett and Nell. 1983). Pressure was increased at a rate of 0.6 MPa per minute until a drop of moisture was seen exuding from the cut portion of the stem, at which time the xylem water potential reading was taken. After being removed from the pressure chamber, the cutting was then weighed. This procedure was then continually repeated on the same cuttings for a total of 12 to 16 cycles. After all measurements were taken, the cuttings were dried in a 70° C drying oven for 1 week and dry weights were determined. A pressure-volume curve was then manually constructed for each plant by plotting the inverse of the water potential versus the corresponding relative water content (RWC). RWC = [(fresh weight of cutting after each cycle - dry weight)/(fresh weight at full hydration - dry weight)] x 100. From each pressure-volume curve, the osmotic potential at full turgor (inverse of y-intercept) and turgor loss point (point at which the linear and curvilinear portions of the PV curve joined) were determined for each plant (Cheung et al., 1976). Data were subjected to analysis of variance and Tukey mean separation.

Experiment 2. This experiment was conducted to investigate the effects of production light levels and water stress on the cellular leaf anatomy, stomatal conductance and growth of Catharanthus roseus 'Cooler Peppermint' at the end of 6 weeks of production. Subsequent landscape performance as affected by production conditions was then studied.

Seedlings were obtained as previously described on 16 Mar. 1995 and transplanted into 10-cm diameter by 8-cm deep plastic azalea containers using Vegro Clay Mix (Vegro Co., Tampa, FL) medium on 17 Mar. Plants were thoroughly watered and spaced on wire mesh benches in a Lexan-covered greenhouse and pruned to one plant per container. Plants were maintained well watered as necessary and never experienced wilting conditions during the subsequent 2-week period. Liquid fertilizer derived from 20% N, 4.3% P, 16.6% K was applied at a concentration of 150 ppm N during each watering throughout the greenhouse portion of the experiment.

On 31 Mar., all plants were placed into a randomized, complete block design with five plants per experimental unit and three replications. The experiment was a 2 x 4 x 2 factorial with 2 production light levels, 4 production water stress regimes and 2 landscape fertilizer levels. Light regimes were "high" (full greenhouse irradiance levels which averaged 1,467 $\mu$mol $m^{-2}$ $s^{-1}$ at midday) and "low" (67% of full greenhouse irradiance levels which averaged 1,033 $\mu$mol $m^{-2}$ $s^{-1}$ at midday). Watering regimes were "WW", "LW+1","W+1" and "W+3".

The date of first flowering for each plant was recorded. The greenhouse production phase of the experiment was terminated on 17 May, and plant height, two plant widths, flower diameter and shoot dry weights were determined for five plants from each light x water treatment. Plant height was measured from the level of the medium to the top of the plant. Two plant width measurements were taken perpendicular to each other and averaged to determine average plant width. Plant width and plant height were added and divided by two to calculate average plant size. Flower diameter was measured on a

terminal flower that was completely open. Shoot dry weight was determined by harvesting all plant tissue above the medium, drying in a 70° C drying oven for 7 days and weighing.

At 0700 hours on 19 May, 10 plants from each light x water treatment were well watered. Between 1300 and 1500 hours on 19 and 20 May, diffusive resistance on the abaxial leaf surface and leaf abaxial water vapor conductance were measured on five plants from each light x water treatment. Conductance was determined with a steady state porometer (Li-Cor, Inc. Model Li-1600), using a 2-$cm^2$ aperture and set for an atmospheric pressure of 104 pPa. Measurements were taken from the youngest, fully-expanded leaf. Stomatal conductance was calculated by taking the inverse of diffusive resistance.

On 4 April., the underside of the most recently expanded leaves of five plants from each greenhouse light x water treatment were marked. On 19 May, a leaf six nodes up from the marked leaf was harvested and its leaf area was determined with a portable leaf area machine (Li-Cor, Inc. Model Li-3000A). Stomatal densities were calculated from microscopic examinations of impressions of the abaxial and adaxial leaf surfaces on clear fingernail polish (Stoddard, 1965). The total stomata per leaf for each side and the grand total of stomata per leaf for both sides were calculated. For anatomical examination, the leaf opposite the one used for stomatal investigations was harvested, killed in FAA, dehydrated in tertiary butyl alcohol, embedded in paraffin, sectioned at 10 $\mu$m and stained with toluidine blue (Sakai, 1973).

Soil in landscape beds had a sand texture, a pH of 6.5, a very high level of available phosphorous (120+ ppm P) and a medium level of available potassium (48 ppm K). Five plants per replication from each greenhouse light x water treatment were planted in each landscape fertilizer treatment area on 20 May. The two fertilizer regimes were "low" (0.38 lbs of N/1000 $ft^2$ with 0.25 lbs of N supplied per month or "high" (1.5 lbs N / 1000 $ft^2$ with 1.0 lbs N supplied per month). The fertilizer used was Nutricote 14-14-14 type 70 (14%N, 3.0% P, 11.6% K) and was incorporated to a depth of approximately 6 inches with a rototiller. Spacing was 12-inches apart. The plants were watered as needed with a drip irrigation system for the duration of the landscape portion of the study. The plants were never allowed to wilt in the field.

Height and two widths were measured on each plant on 20 May, 4 June, 16 June and 2 July. Plant height was measured from the soil level to the top of each plant. The two widths were taken perpendicular to each other and then averaged to determine average plant width. Average plant size was calculated by adding plant height to the average plant width and dividing by two. The landscape portion of the study was terminated on 3 July at which time all tissue above the soil line was harvested, placed in a drying oven at 70° C for 1 week and weighed to determine shoot dry weight. Change in plant height, width and average size was calculated for each 2-week time interval and for the entire time (6 weeks) in the landscape bed. All data were subjected to analysis of variance and Tukey mean separation.

## Results and Discussion

### Effects of Production Environment on Anatomy (Experiment 2)

No interaction between the greenhouse light and water stress levels was found in regards to leaf size at the end of production. The leaf size of plants grown under higher light was significantly smaller than plants grown under low light (Table 4-1). Increasing levels of water stress resulted in significantly smaller leaf sizes (Table 4-1). These effects of production light and water stress levels match results reported on other species (Bebb and Turner, 1976; Boardman, 1977; Boyer, 1970; Connor, 1981; Conover and Poole, 1977; Conover et al., 1982; Fails et al., 1982a, 1982b; Hsiao, 1973; Johnson et al., 1982a; McClendon and McMillen, 1982; Milks et al., 1979; Mott and Michaelson, 1991; Pearson, 1980; Vidal et al., 1990) and show that the light and water stress levels used in this study were different enough from each other to produce differences in plant growth.

Table 4-1 Effects of two greenhouse light levels and four water regimes on leaf size of Catharanthus roseus 'Cooler Peppermint' after 6 weeks of production.

| | Leaf Size ($cm^2$)* | | Leaf Size ($cm^2$)* |
|---|---|---|---|
| Water regime^ | | Light level | |
| WW | 20.2 a | High | 14.3 a |
| LW+1 | 18.6 b | Low | 17.2 b |
| W+1 | 13.7 c | | |
| W+3 | 10.5 d | | |

* Tukey Studentized Range (HSD) Test: means within column followed by the same letter are not different at P=0.01. Means calculated on 5 replicates.

^ Water regime: well watered (WW); wilt maintained for 1 day prior to watering for last 2 weeks of production (LW+1); wilt maintained for 1 day prior to watering (W+1); wilt maintained for 3 days prior to watering (W+3).

Neither light nor water stress treatments had an effect on adaxial stomatal density (Table 4-2). There was a significant interaction (P=0.0001) between greenhouse light and water stress levels on abaxial stomatal density. Leaves grown under high light had higher abaxial stomatal densities than leaves grown under low light for all water stress treatments except the most severe, W+3 (Table 4-2). Similar results on other crops was reported by Conover and McConnell (1981), Cormack and Gorham (1953), Fails et al, (1982a), Givnish, (1988), Johnson et al. (1982a), Lee et al. (1988), Sims and Pearcy (1992) and Vidal et al. (1990). Water stress had no effect on abaxial stomatal density in leaves grown under low light and only produced a difference in leaves grown under high light at the W+3 level, where the density was less (Table 4-2). Ciha and Brun (1975), Manning et al. (1977) and Wang and Clark (1992) reported Phaseolus, Pisum and Triticum, respectively, showed increasing stomatal densities with increasing water stress on both leaf surfaces. They contributed this increase in stomatal density to a decrease in leaf area.

There was a significant interaction (P=0.0092) between greenhouse light and water stress levels on total stomata per leaf. There was not a significant difference in total stomata per leaf between plants grown under high versus low greenhouse light levels (Table 4-3). There was not a significant difference between the WW and LW+1 plants, but increasing water stress from WW to W+1 and W+3 resulted in reduced total number of stomata per leaf (Table 4-3). Because the LW+1 plants were maintained well watered until the last two weeks of the study, the sample leaves had not been exposed to the water stress, accounting for the lack of differences between the WW and LW+1 plants.

Table 4-2 Effects of two greenhouse light levels and four water regimes on stomatal density of Catharanthus roseus 'Cooler Peppermint' after 6 weeks of production.

| | Adaxial stomatal density (stomata/mm$^2$)* | |
|---|---|---|
| Water regime^ | High light level | Low light level |
| WW | 24.0 | 39.2 |
| LW+1 | 22.4 | 35.2 |
| W+1 | 22.4 | 31.2 |
| W+3 | 21.6 | 28.8 |

| | Abaxial stomatal density (stomata/mm$^2$)* | |
|---|---|---|
| Water regime | High light level | Low light level |
| WW | 228 ab | 181 c |
| LW+1 | 229 ab | 193 c |
| W+1 | 215 b | 184 c |
| W+3 | 196 c | 194 c |

* Tukey Studentized Range (HSD) Test: means within each table followed by the same letter (in or between columns) are not different at P=0.05. Means calculated on 15 replicates.

^ Water regime: well watered (WW); wilt maintained for 1 day prior to watering for last 2 weeks of production (LW+1); wilt maintained for 1 day prior to watering (W+1); wilt maintained for 3 days prior to watering (W+3).

Table 4-3 Effects of two greenhouse light levels and four water regimes on total stomata per leaf of Catharanthus roseus 'Cooler Peppermint' after 6 weeks of production.

| | Total stomata per leaf* | |
|---|---|---|
| Water regime^ | High | Low |
| WW | 47,500 ab | 49,700 a |
| LW+1 | 42,800 b | 46,800 ab |
| W+1 | 29,600 c | 33,600 c |
| W+3 | 20,800 d | 21,700 d |

* Tukey Studentized Range (HSD) Test: means followed by the same letter (in or between columns) are not different at P=0.05. Means calculated on 5 replicates.
^ Water regime: well watered (WW); wilt maintained for 1 day prior to watering for last 2 weeks of production (LW+1); wilt maintained for 1 day prior to watering (W+1); wilt maintained for 3 days prior to watering (W+3).

This study demonstrated that greenhouse light and water stress levels affect the final leaf area and abaxial stomatal density of Catharanthus. The plants that were grown under the high light level had smaller leaf sizes and greater abaxial stomatal densities at the end of 6 weeks of production, although they had the same total number of stomata per leaf as the plants grown under the low light.

In regards to water stress, Ciha and Brun (1975) and Knecht and O`Leary (1972) reported that stomatal densities increased with increasing water stress due to decreases in leaf area, the total number of stomata per leaf remained fairly constant. In the present study, stomatal densities were not affected by increasing water stress even though leaf areas decreased. As a result, the total number of stomata per leaf decreased with increasing water stress.

Greenhouse light and water stress levels also had effects at the cellular level. Smaller ground parenchyma cells, particularly at the base of the petiole, and smaller intercellular spaces were evident with increasing water stress during production (Figures 4-1 and 4-2). An increase in xylem cell wall thickening due to sclerification and a decrease in xylem cell diameter were also the results of increasing water stress (Figures 4-3 and 4-4). Manning et al (1977) found similar results in Pisum grown under various degrees of moisture stress. The development of a double palisade mesophyll layer became more evident as water stress increased in plants grown under the high light (Figure 4-5). McConnell and Host (1983) reported this doubling of the palisade mesophyll layer in water-stressed Pereskia. For plants grown under the low light level, the palisade mesophyll layer became more disrupted with increased water stress but did not appear to become double as seen for the high light plants (Figure 4-6). Also for the low light plants, the spongy mesophyll cells became smaller and more compacted with increased water stress when compared with the control plants (Figure 4-6). These findings are consistent with those of Treeshow (1970), Cutler et al. (1977), Manning et al. (1977) and Nobel (1977). Smaller mesophyll cells result in a greater $A^{mes}/A$ (mesophyll surface area per unit leaf area). A greater $A^{mes}/A$ was shown to increase photosynthetic rates and increase water use efficiency in some species (LeCain et al., 1989; Patton and Jones, 1989). In terms of the upper epidermal cells of the leaf blade, increasing water stress produced smaller and less isodiametric cells. (Figure 4-7). McBurney (1992) reported similar findings in drought-stressed Brassica. No visual differences in leaf blade thicknesses were observed between either the light or water stress treatments. Other researchers (Boardman, 1977; Conover and Poole, 1977;

Conover et al., 1982; Fails et al., 1982a, 1982b; Johnson et al., 1982a; McClendon and McMillen, 1982; Milks et al., 1979; Mott and Michaelson, 1991; Vidal et al., 1990) reported thicker leaves for plants grown in full sun. As noted above, most of the anatomical differences observed were due to the water stress treatments rather than the light level treatments.

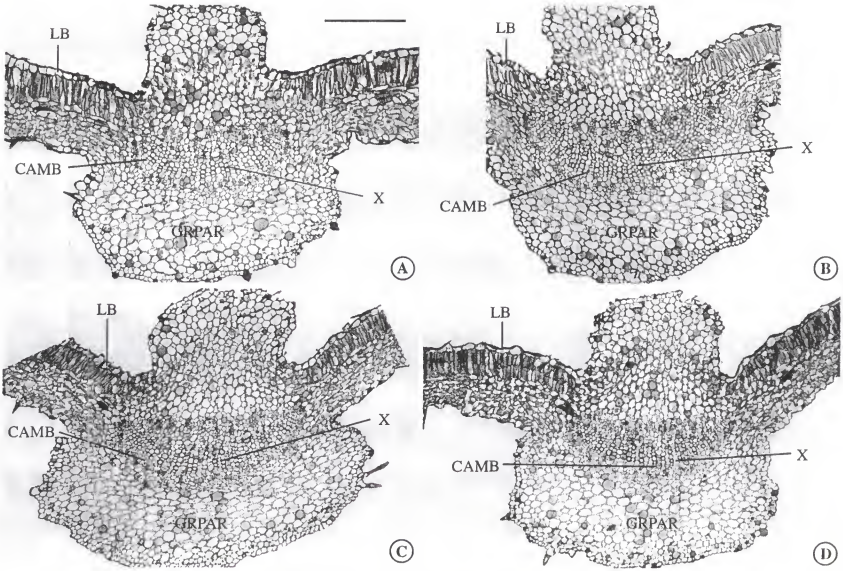


Figure 4-1 Cross-section through leaf petiole that expanded during production in high light. A - WW, B - LW+1, C - W+1, D - W+3. LB - leaf blade. CAMB - cambium. X - xylem. GRPAR - ground parenchyma. Dimension bar = 22 mm.

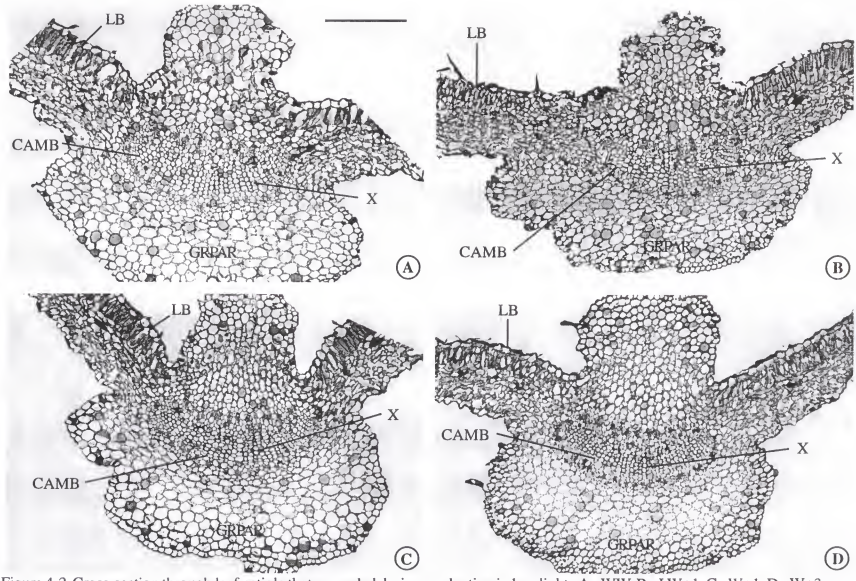


Figure 4-2 Cross-section through leaf petiole that expanded during production in low light. A - WW, B - LW+1, C - W+1, D - W+3. LB - leaf blade. CAMB - cambium. X - xylem. GRPAR - ground parenchyma. Dimension bar = 22 mm.

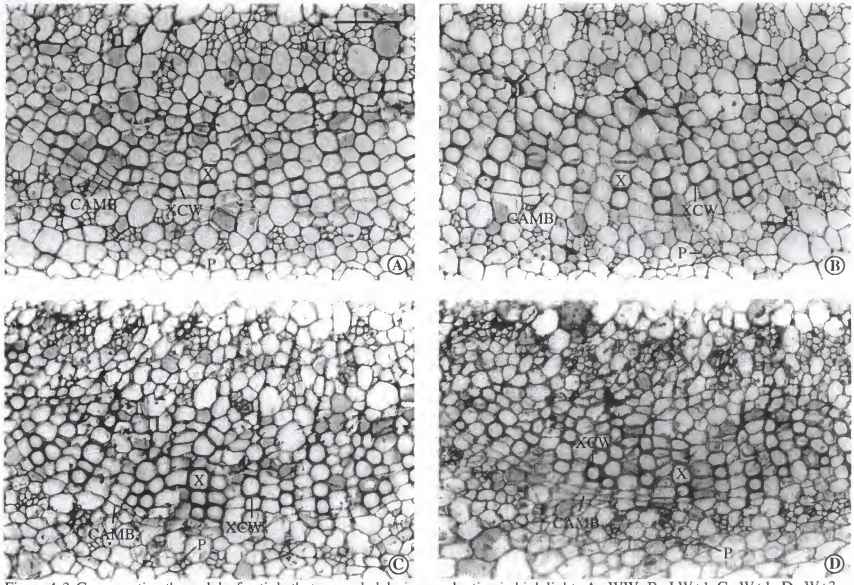


Figure 4-3 Cross-section through leaf petiole that expanded during production in high light. A - WW, B - LW+1, C - W+1, D - W+3. LB - Leaf blade. CAMB - cambium. X - xylem. XCW - xylem cell wall. P - phloem. Dimension bar = 18mm.

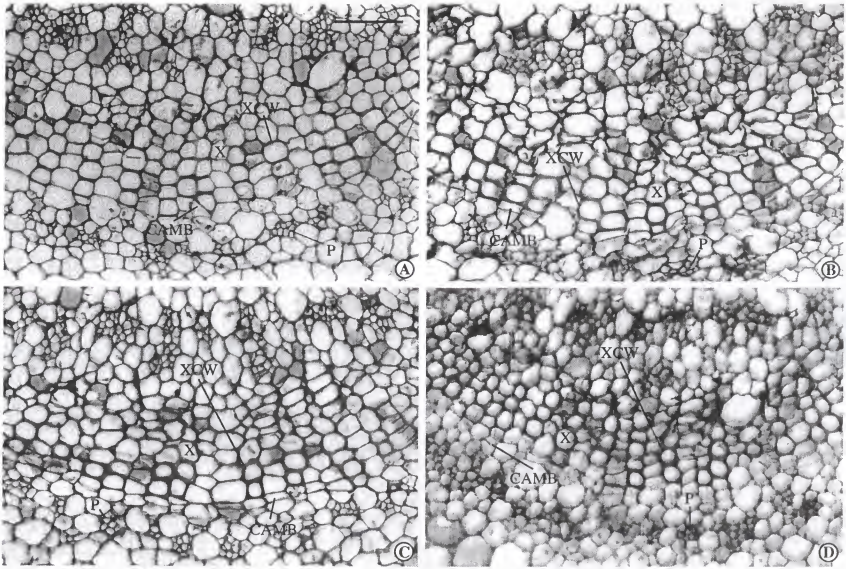


Figure 4-4 Cross-section through leaf petiole that expanded during production in low light. A - WW, B - LW+1, C - W+1, D - W+3. LB - Leaf blade. CAMB - cambium. X - xylem. XCW - xylem cell wall. P - phloem. Dimension bar = 18 mm.

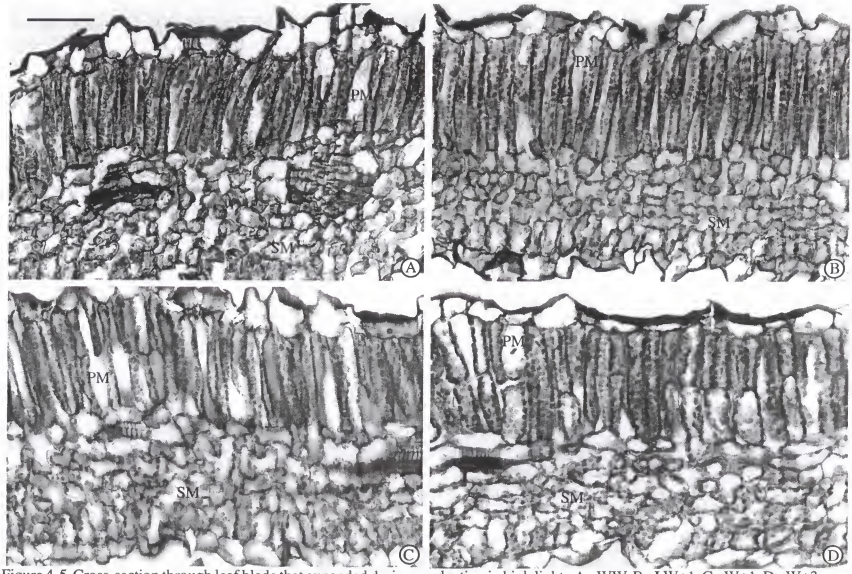


Figure 4-5 Cross-section through leaf blade that expanded during production in high light. A - WW, B - LW+1, C - W+1, D - W+3. LB - leaf blade. PM - palisade mesophyll. SM - spongy mesophyll. Dimension bar = 18 mm.

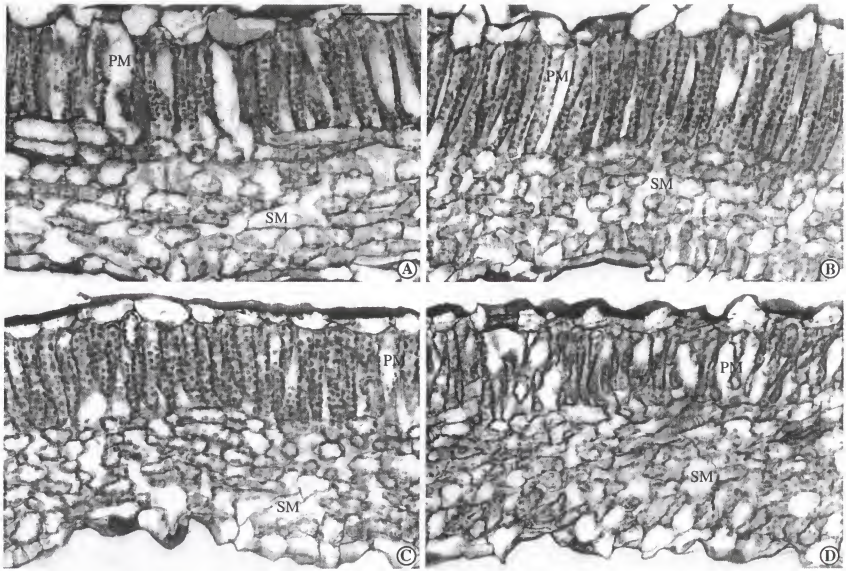


Figure 4-6 Cross-section through leaf blade that expanded during production in low light. A - WW, B - LW+1, C - W+1, D - W+3. LB - leaf blade. PM - palisade mesophyll. SM - spongy mesophyll. Dimension bar = 18 mm.

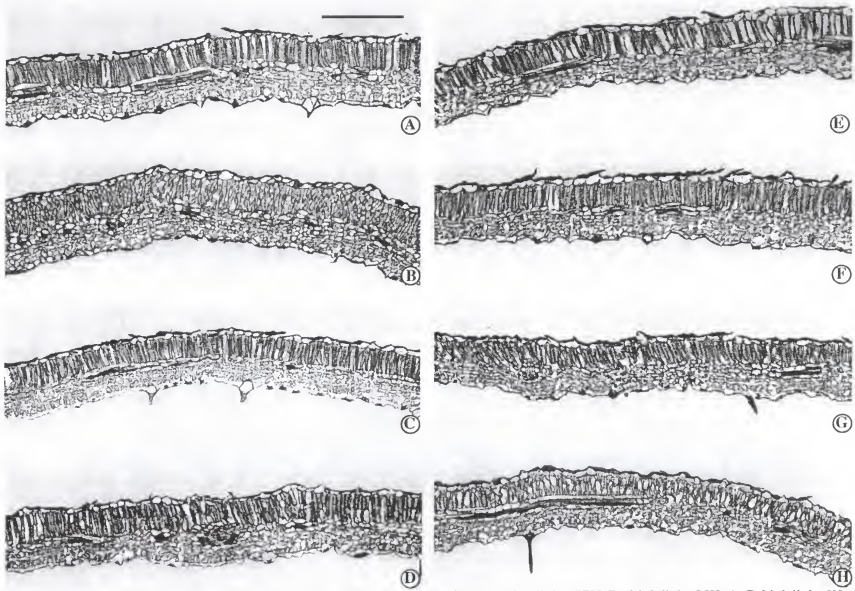


Figure 4-7 Cross-section through leaf blade that expanded during production. A - high light, WW. B - high light, LW+1. C -high light, W+1. D - high light, W+3. E - low light, WW. F - low light, LW+1. G - low light, W+1. H - low light, W+3. Dimension bar = 22 mm.

Effects of Production Environment on Physiology (Experiments 1 and 2)

Osmotic Adjustment

Pressure-volume curves were constructed to calculate osmotic potential at full turgor, osmotic adjustment and water potentials for turgor loss points. All water stress levels produced lower osmotic potentials than the WW controls (Table 4-4). No significant differences in osmotic potential were found between the three water stress levels under high light. Due to constraints imposed by the research procedure, the only comparison made between plants grown at high versus low light levels was for the W+1 treatment. For the W+1 treatment, plants grown under the high light levels exhibited a lower osmotic potential.

The osmotic potentials of the other treatments were subtracted from the osmotic potential of the WW controls to determine the amount of osmotic adjustment that occurred during production (Table 4-4). Plants from all water stress levels underwent osmotic adjustment compared to the WW controls. That moisture stress conditioning can result in osmotic adjustment in Catharanthus agrees with the findings reported by Virk and Singh (1990). For the W+1 treatment, plants grown under high light showed a greater amount of osmotic adjustment than plants grown under lower light (Table 4-4). No significant differences in osmotic adjustment were found between the three water stress levels under high light. These results indicate that increasing the severity and/or earliness of water stress during production of Catharanthus does not significantly increase the amount of osmotic adjustment that occurs.

When compared with the WW controls, plants from all treatments lost turgor at a lower water potential (Table 4-4). Eakes et al. (1991b) reported similar findings with moisture stress conditioned Salvia. No significant differences were found between the three water stress levels under either light level, once again indicating no physiological benefit from more severe and/or earlier water stress with growing Catharanthus.

Table 4-4 Effects of two greenhouse light levels and four water regimes on the osmotic potential at full turgor, osmotic adjustment and turgor loss points of Catharanthus roseus 'Cooler Peppermint' after 6 weeks of production.

| Water x Light treatment^ | Osmotic potential at full turgor (MPa)* | Osmotic adjustment[z] (MPa)* | Turgor loss point (MPa)* |
|---|---|---|---|
| WW*High | -1.18 c | -0.00 a | -1.43 b |
| LW+1*High | -1.47 ab | -0.29 bc | -1.67 a |
| W+1*High | -1.51 a | -0.33 b | -1.75 a |
| W+1*Low | -1.41 b | -0.23 c | -1.66 a |
| W+3*High | -1.53 a | -0.35 b | -1.72 a |

* Tukey Studentized Range (HSD) Test: means followed by the same letter (in columns) are not different at P=0.05. Means calculated on 10 replicates.

^ Water regime: well watered (WW); wilt maintained for 1 day prior to watering for last 2 weeks of production (LW+1); wilt maintained for 1 day prior to watering (W+1); wilt maintained for 3 days prior to watering (W+3).

[z] Osmotic adjustment = osmotic potential of WW control - osmotic potential of treatment

Stomatal Conductance

There was a significant interaction (P=0.0001) between greenhouse light and water stress levels for stomatal conductance of plants measured at the end of 6 weeks of production on 19 May. For the WW control and the LW+1 treatment, plants grown under high light had higher stomatal conductances than plants grown under low light (Table 4-5). Stomatal conductance was reported to be higher for leaves produced under sun versus shade for other species (Boardman, 1977; Bjorkman, 1981; Mott and Michaelson, 1991). This effect is most likely due to leaves produced under higher light having higher stomatal densities, as reported earlier in this study on Catharanthus. There were no differences due to light for the W+1 and W+3 treatments (Table 4-5). For plants produced under high light, increasing water stress resulted in lower stomatal conductances, with W+1 and W+3 not being significantly different from each other. Other researchers have also shown that moisture stress conditioning can reduce leaf conductance and/or transpiration (Eakes et al., 1991a; Edwards and Dixon, 1995; Kaufmann and Levy, 1976; Pearson, 1980). The reductions in stomatal conductance in the above studies were attributed to a reduction in stomatal aperture. The reductions in stomatal conductance in this study on Catharanthus can be explained, at least in part, by the reduced abaxial stomatal densities due to water stress that were earlier reported. Even though stomatal aperture was not measured in this study, it most likely had a role as well in the stomatal conductance results reported here. Moisture stress conditioning can increase ABA concentrations in the stomata guard cells, causing them to partially or

completely close (Zang et al., 1987). There is a lag time after the plants again receive water before the stomata return to their pre-stressed aperture. The effect of increasing water stress on stomatal conductance was not as dramatic for plants produced under low light. Perhaps the stomata guard cell ABA concentrations did not increase as much due to increasing water stress or the guard cells were less sensitive to ABA under lower light conditions. All water stress levels under lower light resulted in stomatal conductances statistically equal to each other, but were all lower than the WW control (Table 4-5).

Table 4-5 Effects of two greenhouse light levels and four water regimes on the stomatal conductance of Catharanthus roseus 'Cooler Peppermint' on 19 May 1995 at 1300 hours.

| | Stomatal conductance (mmol $m^{-2}$ $sec^{-1}$)* | |
|---|---|---|
| Water regime^ | High | Low |
| WW | 751 a | 590 b |
| LW+1 | 574 b | 428 cd |
| W+1 | 392 cd | 446 c |
| W+3 | 336 d | 437 cd |

* Tukey Studentized Range (HSD) Test: means followed by the same letter (in or between columns) are not different at P=0.05. Means calculated on 15 replicates.
^ Water regime: well watered (WW); wilt maintained for 1 day prior to watering for last 2 weeks of production (LW+1); wilt maintained for 1 day prior to watering (W+1); wilt maintained for 3 days prior to watering (W+3).

The same plants measured above were allowed to dry down for 24 hours. Diffusive resistances were measured again at 1300 hours and stomatal conductances were calculated (Table 4-6). There was a significant interaction (P=0.0029) between greenhouse light and water stress levels. The only situation where light levels produced a significant effect was for the WW controls, where stomatal conductance was higher for the plants grown under

the high light. For plants produced under both light levels, increasing production water stress regimes generally resulted in higher stomatal conductances. The differences between the three production water stress treatments under the high light were not statistically different from each other. The low light only resulted in differences between the LW+1 and W+1 plants. The results from the second day are not surprising when one takes into account the fact that the plants' total leaf areas were not equal (Table 4-7). With each increasing level of production water stress, the finished plants had smaller total leaf areas. Other researchers reported similar effects of moisture stress on leaf area (Nash and Graves, 1993; Manning et al., 1977; Martens, 1988). Reductions in leaf areas due to moisture stress are attributed to lower water potentials available for cell expansion (Boyer, 1970). Because the WW controls had the largest total leaf area, they had depleted the available water supply in the container medium by the time the second measurements were taken. This water stress caused these plants to close their stomata which resulted in their very low stomatal conductances on the second day. The stomatal conductances of the LW+1, W+ 1 and W+3 plants were still high the second day because they had less total leaf area to deplete the container medium water supply and thus were not experiencing as much water stress. The LW+1, W+1 and W+3 plants also underwent osmotic adjustment as previously reported, which may have also contributed to these plants being able to maintain higher stomatal conductances after this 24 hours of dry down.

Table 4-6 Effects of two greenhouse light levels and four water regimes on the stomatal conductance of Catharanthus roseus 'Cooler Peppermint' on 20 May 1995 at 1300 hours.

| | Stomatal conductance (mmol $m^{-2}$ $sec^{-1}$)* | |
|---|---|---|
| Water regime^ | High | Low |
| WW | 53 d | 13 e |
| LW+1 | 199 bc | 132 c |
| W+1 | 235 ab | 285 a |
| W+3 | 265 ab | 265 ab |

* Tukey Studentized Range (HSD) Test: means followed by the same letter (in or between columns) are not different at P=0.05. Means calculated on 15 replicates.
^ Water regime: well watered (WW); wilt maintained for 1 day prior to watering for last 2 weeks of production (LW+1); wilt maintained for 1 day prior to watering (W+1); wilt maintained for 3 days prior to watering (W+3).

Table 4-7 Effects of two greenhouse light levels and four water regimes on total leaf area of Catharanthus roseus 'Cooler Peppermint' after 6 weeks of production.

| | Total leaf area ($cm^{-2}$)* | |
|---|---|---|
| Water regime^ | High | Low |
| WW | 1780 a | 1600 b |
| LW+1 | 1620 ab | 1410 c |
| W+1 | 851 d | 824 d |
| W+3 | 639 e | 599 e |

* Tukey Studentized Range (HSD) Test: means followed by the same letter (in or between columns) are not different at P=0.05. Means calculated on 15 replicates.
^ Water regime: well watered (WW); wilt maintained for 1 day prior to watering for last 2 weeks of production (LW+1); wilt maintained for 1 day prior to watering (W+1); wilt maintained for 3 days prior to watering (W+3).

Whole-plant Transpiration

Transpiration per unit leaf area (mmol $m^{-2}$ $s^{-1}$) was calculated between 0900 and 1300 hours after 6 weeks of production (Table 4-8). There was a significant interaction between greenhouse light and water stress treatments (P=0.0002). No differences due to production light levels were found in any of the water treatments. Also, no differences were discovered among any of the three water stress treatments. However, for plants grown under the high light level, all water stress levels resulted in plants that transpired less than the WW controls. The lag affect of ABA concentrations on stomatal opening could explain this finding. For plants grown under the lower light level, the only plants to transpire less than the WW controls were the plants given the LW+1 water stress treatment. When Catharanthus is grown under high light conditions, water loss due to transpiration could be reduced in retail and/or landscape settings by producing the plants under a water stress regime.

The current industry practice of growing the plants well watered until the last two weeks of production appears to be the best approach for reducing future water loss due to transpiration for both high and low light produced Catharanthus. Growing the plants under more severe and earlier water stress conditions did not reduce transpiration rates after 6 weeks of production . How long the affect of these production treatments would carry over into a retail and/or landscape setting was not evaluated in this study. Armitage (1986) reported that a less frequent irrigation regime during production did increase the postproduction life of petunias compared to a more frequent regime. The effect of

irrigation frequency on transpiration rates either at the end of production or later in the plant's life was not measured in the above study.

Table 4-8 Effects of two greenhouse light levels and four water regimes on transpiration of Catharanthus roseus 'Cooler Peppermint' between 0900 and 1300 hours after 6 weeks of production.

| | Transpiration/unit leaf area (mmol $m^{-2}$ $s^{-1}$)* | |
|---|---|---|
| Water regime^ | High | Low |
| WW | 28.4 a | 26.6 ab |
| LW+1 | 23.2 cd | 21.8 d |
| W+1 | 22.7 cd | 25.1 abcd |
| W+3 | 24.9 bcd | 24.8 bcd |

* Tukey Studentized Range (HSD) Test: means followed by the same letter (in or between columns) are not different at P=0.05. Means calculated on 15 replicates.
^ Water regime: well watered (WW); wilt maintained for 1 day prior to watering for last 2 weeks of production (LW+1); wilt maintained for 1 day prior to watering (W+1); wilt maintained for 3 days prior to watering (W+3).

Greenhouse Growth

The effects of two greenhouse light levels and four water regimes on flowering date, flower size, plant height, plant width, plant size and shoot dry weight were determined after six weeks of treatments. There was no interaction between light and water stress levels on date to first flower. Plants produced under high light flowered 2.5 days later than plants grown under low light (Table 4-9). Increasing water stress delayed flowering (Table 4-9). There was a significant interaction (P=0.0373) between light and water stress levels for flower diameter. The only difference due to light level was found for the W+3 plants, where plants grown under high light had larger flower diameters than plants

grown under low light (Table 4-10). Increasing water stress tended to reduce flower size (Table 4-10). All flower diameter differences due to water stress treatments were significantly different from each other except LW+1 was equal to W+1 for both light levels (Table 4-10).

Table 4-9 Effects of two greenhouse light levels and four water regimes on days to first flower of Catharanthus roseus 'Cooler Peppermint' during greenhouse production.

| | Days to first flower* | | Days to first flower* |
|---|---|---|---|
| Water regime^ | | Light level | |
| WW | 23.1 b | High | 25.7 a |
| LW+1 | 22.3 a | Low | 23.2 b |
| W+1 | 25.0 c | | |
| W+3 | 27.3 d | | |

* Tukey Studentized Range (HSD) Test: means within column followed by the same l letter are not different at P=0.05. Means calculated on 15 replicates.

^ Water regime: well watered (WW); wilt maintained for 1 day prior to watering for last 2 weeks of production (LW+1); wilt maintained for 1 day prior to watering (W+1); wilt maintained for 3 days prior to watering (W+3).

Table 4-10 Effects of two greenhouse light levels and four water regimes on flower diameter of Catharanthus roseus 'Cooler Peppermint' after 6 weeks of production.

| | Flower diameter (cm)* | |
|---|---|---|
| Water regime^ | High | Low |
| WW | 5.08 a | 4.99 a |
| LW+1 | 4.57 b | 4.52 b |
| W+1 | 4.63 b | 4.41 b |
| W+3 | 4.05 c | 3.56 d |

* Tukey Studentized Range (HSD) Test: means followed by the same letter (in or between columns) are not different at P=0.05. Means calculated on 15 replicates.
^ Water regime: well watered (WW); wilt maintained for 1 day prior to watering for last 2 weeks of production (LW+1); wilt maintained for 1 day prior to watering (W+1); wilt maintained for 3 days prior to watering (W+3).

No interaction was found between light and water stress levels for plant height, average width or plant size at the end of 6 weeks of greenhouse production. The two light levels did not result in plant height, width or size differences. Water stress levels had an effect on plant height, width and size (P=0.0001). Increasing water stress produced shorter plants, narrower plants and smaller plants (Table 4-11). Manning et al. (1977), Martens (1988) and White and Holcomb (1974) have also shown the effects of moisture stress in reducing plant height. Moisture stress limits plant growth by reducing turgor levels necessary for cell division and elongation and by reducing essential metabolic processes required for plant growth and development (Hsiao, 1973). The results of this study show that water stress is an effective means of controlling plant size in Catharanthus.

Table 4-11 Effects of four greenhouse water regimes on height, width and size of Catharanthus roseus 'Cooler Peppermint' after 6 weeks of production.

| Water regime^ | Height (cm)* | Width (cm)* | Size (cm)* |
|---|---|---|---|
| WW | 24.1 a | 27.1 a | 25.6 a |
| LW+1 | 21.0 b | 23.4 b | 22.2 b |
| W+1 | 15.6 c | 17.2 c | 16.4 c |
| W+3 | 12.9 d | 14.6 d | 13.7 d |

* Tukey Studentized Range (HSD) Test: means within column followed by the same letter are not different at P=0.05. Means calculated on 15 replicates.
^ Water regime: well watered (WW); wilt maintained for 1 day prior to watering for last 2 weeks of production (LW+1); wilt maintained for 1 day prior to watering (W+1); wilt maintained for 3 days prior to watering (W+3).

A significant interaction between light and water stress levels was found for shoot dry weight at the end of 6 weeks of greenhouse production (P=0.0042). Difference dues to light were found only at the WW and LW+1 water stress levels where plants grown under low light had a higher shoot dry weight (7.19 versus 6.1 g for WW plants and 5.75 versus 4.89 g for LW+1 plants). Greater water stress resulted in less shoot dry weight under both light levels, except there was no differences between W+1 and W+3 for plants grown under high light. Other researchers (Eakes et al, 1991a; Latimer, 1990; VanDerZanden, 1994) have reported similar reductions in shoot dry weights from water stress.

Landscape Growth

No significant interactions among greenhouse light x greenhouse water x field fertilizer, greenhouse light x field fertilizer or between greenhouse water x field fertilizer were found for any measures of plant performance measured between 0 and 6 weeks in

the field. Fertilizer rate had a significant effect on change in width and size between 0 and 2 weeks and change in height, width, size and shoot dry weight between 0 and 6 weeks in the field (Table 4-12). The higher fertilizer rate resulted in plants that were taller, wider, larger and with greater shoot dry weights. There was no difference between fertilizer rates for change in height between 0 and 2 weeks. The results of this field study show the importance of nutrient availability for more rapid establishment and growth of Catharanthus in a landscape setting.

Table 4-12 Effect of two slow-release fertilizer rates on the growth of Catharanthus roseus 'Cooler Peppermint' in a field landscape setting between 20 May and 2 Jul. 1995. Data averaged for all greenhouse treatments.

| | Growth (cm)* | | | | | | Mass (g)* |
|---|---|---|---|---|---|---|---|
| Ferti-lizer. | Change in Ht. after 2 weeks | Change in Ht. after 6 weeks | Change in Width after 2 weeks | Change in Width after 6 weeks | Change in Size after 2 weeks | Change in Size after 6 weeks | Shoot Dry Wt. after 6 weeks |
| High | 1.74 a | 11.40 a | 4.14 a | 20.20 a | 2.94 a | 15.80 a | 35.60 a |
| Low | 1.72 a | 8.17 b | 2.21 b | 13.00 b | 1.97 b | 10.60 b | 26.50 b |

*Tukey Studentized Range (HSD) Test: means followed by the same letter (in columns) are not different at P=0.05. Means calculated on 15 replicates.

There was a significant interaction between greenhouse light and water stress levels for the change in height (P=0.0332) and change in size (P=0.0247) between 0 and 2 weeks in the field. Only greenhouse water stress levels had a significant affect (P=0.001) on change in plant width. Greenhouse light levels had no effect on change in plant height (Table 4-13). Height growth differences were only found between the LW+1 and W+3 plants that were grown under the high light (Table 4-13). The W+3 plants grew more in height.

Increasing greenhouse water stress levels resulted in greater increases in plant widths between 0 and 2 weeks in the field (WW, 0.97; LW+1, 2.77; W+1, 4.20; W+3, 4.79 cm). The LW+1 and W+1 treatments were statistically similar, as were W+1 and W+3. Greenhouse light levels had no effect on change in plant size between 0 and 2 weeks in the field (Table 4-13). Increasing levels of greenhouse water stress resulted in greater changes in plant size (Table 4-13). This study shows that growing Catharanthus in a greenhouse under moderate to severe water stress cycles can cause a greater change in plant size during the first 2 weeks of establishment in a landscape field setting.

Table 4-13 Effects of two greenhouse light levels and four water regimes on the change in plant height and size of Catharanthus roseus 'Cooler Peppermint' between 0 and 2 weeks in the field.

| | Change in plant height (cm)* | |
|---|---|---|
| Water regime^ | High | Low |
| WW | 3.00 ab | 1.38 b |
| LW+1 | 1.70 b | 1.96 b |
| W+1 | 2.93 ab | 1.73 b |
| W+3 | 4.12 a | 2.24 ab |
| | Change in plant size (cm)* | |
| Water regime^ | High | Low |
| WW | 1.39 cd | 1.00 d |
| LW+1 | 0.91 d | 2.10 bcd |
| W+1 | 3.56 ab | 2.86 bc |
| W+3 | 4.67 a | 3.21 abc |

* Tukey Studentized Range (HSD) Test: means within the same table followed by the same letter (in or between columns) are not different at P=0.05.

^ Water regime: well watered (WW); wilt maintained for 1 day prior to watering for last 2 weeks of production (LW+1); wilt maintained for 1 day prior to watering (W+1); wilt maintained for 3 days prior to watering (W+3).

A significant interaction between greenhouse light and water stress levels did not occur for changes in plant height, width, size and shoot dry weights between 0 and 6 weeks in the field. It was also found that greenhouse light levels by themselves produced no significant differences for any of the above parameters. Increasing levels of greenhouse water stress did result in greater changes in plant height, width and size between 0 and 6 weeks in the field (Table 4-14). Even though plants grown in the greenhouse under increasing water stress grew more in size after 6 weeks in the field, their shoot dry weight gains were less (Table 4-14). This finding could be due to differences in leaf and stem thicknesses, leaf and stem numbers and/or distribution of photosynthates to shoot versus root tissues. This study shows that growing Catharanthus in a greenhouse under moderate to severe water stress cycles can cause greater changes in plant size 6 weeks after being established in a landscape field setting.

Table 4-14 Effects of four greenhouse water regimes on the change in plant height, width, size and shoot dry weight of Catharanthus roseus 'Cooler Peppermint' between 0 and 6 weeks in the field.

| | Growth (cm)* | | | Mass (g)* |
|---|---|---|---|---|
| Water regime^ | Change in Ht. after 6 wks. | Change in Width after 6 wks. | Change in Size after 6 wks. | Change in shoot dry wt. after 6 wks. |
| WW | 8.81 bc | 13.68 c | 11.24 b | 30.26 a |
| LW+1 | 7.85 c | 15.26 bc | 11.55 b | 29.12 a |
| W+1 | 10.30 ab | 18.15 a | 14.22 a | 25.21 b |
| W+3 | 12.21 a | 19.52 a | 15.86 a | 22.90 b |

* Tukey Studentized Range (HSD) Test: means followed by the same letter (in columns) are not different at P=0.05. Means calculated on 15 replicates.

^ Water regime: well watered (WW); wilt maintained for 1 day prior to watering for last 2 weeks of production (LW+1); wilt maintained for 1 day prior to watering (W+1); wilt maintained for 3 days prior to watering (W+3).

There was not a significant two or three-way interaction among the greenhouse light and water stress levels and the field fertilizer rates for overall plant size between 0 and 6 weeks in the landscape. Increasing levels of greenhouse water stress resulted in smaller plants (P=0.0001)(Table 4-15). The high fertilizer rate produced the largest plants (P=0.0001)(Table 4-15). Since the plants from the various treatments were not all the same size when they were planted in the field, looking at the final size after 6 weeks would not give as accurate picture of what growth actually occurred in the field as looking at changes in plant size. For example the WW plants finished in the field with the largest size, but they also started in the field with the largest size (Table 4-11). In reality, the WW plants exhibited the smallest change in size during the 6 weeks in the field (Table 4-14). The WW plants were installed into the field in this study at a larger size than they would normally be in a commercial situation. Since the goal of bedding plant establishment in the field is to have the plants fill in and touch as quickly as possible, moisture stress conditioning during production at the W+1 level would best achieve this goal without significantly delaying production time or flower size.

Table 4-15. Effects of four greenhouse water regimes and two field fertilizer rates on the overall plant size of Catharanthus roseus 'Cooler Peppermint' between 0 and 6 weeks in the field.

| Water regime^ | Overall size (cm)* | Field Fertilizer | Overall size (cm)* |
|---|---|---|---|
| WW | 37.6 a | High | 37.0 a |
| LW+1 | 35.8 b | Low | 32.0 b |
| W+1 | 32.8 c | | |
| W+3 | 31.8 d | | |

* Tukey Studentized Range (HSD) Test: means followed by the same letter (in columns) are not different at P=0.05. Means calculated on 15 replicates.

^ Water regime: well watered (WW); wilt maintained for 1 day prior to watering for last 2 weeks of production (LW+1); wilt maintained for 1 day prior to watering (W+1); wilt maintained for 3 days prior to watering (W+3).

The greenhouse light and water stress levels evaluated in this study produced anatomical and physiological differences in Catharanthus. The changes due to water stress allowed for improved landscape establishment and growth. Even though the two greenhouse light levels resulted in plants with different leaf areas, stomatal densities, stomatal conductances and degrees of osmotic adjustment, no effects due to light were detected on the field growth of Catharanthus either after 2 or 6 weeks. Perhaps this is due to the fact that the two light levels did not produce plants with differences in total stomata per leaf, transpiration per unit leaf area or in turgor loss points, all factors that have a great influence over plant water status and photosynthetic capacity. It should be noted again that plants in this study did not experience noticeable water stress (i.e. wilting) in the field, although some stress may have occurred that would affect stomatal closure (Bates and Hall, 1981, 1982; Blackman and Davies, 1985; Davies et al., 1980; Gollan et al., 1986,

Gowing et al., 1990; Kuppers et al., 1988; Passioura, 1988; Saab and Sharp, 1989; Zhang and Davies, 1989, 1990a; Zhang et al., 1987). That these two production light levels did not help nor hinder the establishment of Catharanthus in the field under well watered conditions gives growers some leeway on what light levels they may consider for growing this particular crop if postproduction performance is a concern.

Moisture stress conditioning of Catharanthus during greenhouse production benefitted landscape establishment and growth. The goal of establishing ornamental bedding plants in a landscape setting is to have them fill in the bed and flower as quickly as possible. Unlike establishing vegetable transplants in the field, where the goal is to maximize yield, increase in plant size is given a higher emphasis for ornamental bedding plants over increase in shoot dry weight. Increasing water stress levels in the greenhouse resulted in increased plant height, width and size to a small extent after 2 weeks in the field. After 6 weeks in the field, however, a much greater increase in plant height, width and size was realized by growing the plants under increasingly severe water stress cycles in the greenhouse. Since there was not a significant difference between the W+1 and W+3 treatments, it is suggested that the W+1 treatment be used so as not to delay greenhouse flowering and/or reduce flower size without realizing any added benefit in postproduction performance. Latimer (1990, 1991) did not find any improvement in field establishment of Brassica oleracea, Zinnia or Tagetes when plants were moisture stress conditioned in the greenhouse. However, the plants were only allowed to wilt for 2-4 hours before being rewatered. Drought conditioning in the greenhouse decreased lateral growth and quality of Impatiens in the field (Laitmer, 1991).

Moisture stress conditioning during greenhouse production resulted in anatomical and physiological changes that could account for the improved growth in the field. Energy for plant establishment in the field must come from stored carbohydrates, readily available sugars and/or from the production of new sugars. If the production level of new sugars can at least be maintained once the plants are placed into the field, then establishment and growth should exceed that of plants whose sugar production decreases due to water conserving measures such as closing stomata, forcing the plant to deplete stored food reserves. The anatomical and physiological changes reported in this study resulted in plants that were potentially able to better tolerate moisture stresses in the field without reducing photosynthetic capacity. For example, increasing greenhouse water stress resulted in plants with smaller spongy mesophyll cells which results in a greater $A^{mes}/A$ that can lead to increased photosynthetic rates and water-use efficiency (LeCain et al, 1989; Patton and Jones, 1989). Increasing greenhouse water stress produced plants that had fewer total stomata per leaf. The reduction in stomata density explained why transpiration per unit leaf area was lower for plants grown under increasing water stress levels (Rajapakse et al, 1988; Rutland et al, 1987). Stomatal conductances were also found to be lower for moisture-stress-conditioned plants. Therefore, even under conditions where field soil moisture was adequate, plants that were grown under water stress conditions lost less water due to reductions in stomatal apertures (Burrows and Milthorpe, 1976). Plants that lose less water, either due to fewer stomata and/or smaller apertures, were better able to maintain mesophyll water potentials necessary to keep photosynthesis from declining. In spite of fewer stomata and lower stomatal

conductances which would reduce the amount of carbon dioxide entering the mesophyll, moisture stress conditioned plants were apparently able to maintain photosynthesis at a level which resulted in more growth in the field compared to the well watered controls. The ability of moisture stress conditioned plants to maintain turgor at lower water potentials due to fewer stomata and/or lower stomatal conductances and greater osmotic adjustment outweighed the reduced amounts of carbon dioxide entering the leaf.

Plants from all greenhouse water stress levels were shown to have osmotically adjusted compared to the WW controls. This osmotic adjustment allowed the plants to reach lower water potentials before losing turgor. Maintaining cell turgor and chloroplast volume allowed photosynthesis to continue at these lower water potentials (Eakes et al., 1991b; Gupta and Berkowitz, 1987; Matthews and Boyer, 1984; McCree, 1986). How long this benefit from osmotic adjustment continued without the plants being subjected to more water stress cycles was not certain. However, it has been shown to last long enough to keep plants from experiencing as much water stress during the critical first week of field establishment (Jones and Rawson, 1979).

From the treatments evaluated in this study, it is recommended that Catharanthus roseus 'Cooler Peppermint' be produced under either light level with a water regime consisting of allowing the plants to wilt for one day between thorough waterings, beginning 2 weeks after plugs are transplanted. This treatment will result in compact, well-proportioned plants acceptable for shipping and marketing that will establish quickly in a landscape bed setting. A water regime that is any more stressful will not yield any significant gain in landscape growth relative to the increased production time

and reduction in flower size.

# CHAPTER 5
# EFFECTS OF PRODUCTION FERTILIZER, WATER REGIME AND UNICONAZOLE ON THE GREENHOUSE GROWTH AND LANDSCAPE PERFORMANCE OF CATHARANTHUS ROSEUS 'COOLER PEPPERMINT'

## Introduction

Because of economic factors, a goal of most commercial greenhouse producers of ornamental bedding plants is to produce as many crops as possible during the season. For many crops, the use of high levels of water and fertilizer are necessary to achieve this fast growth rate. Chemical growth retardants are used to produce a compact plant so it will be of acceptable size for shipping and marketing. Many of these greenhouse practices are being shown to have negative effects on the postproduction performance of these bedding plants (Armitage, 1993). Plant conditioning, or hardening, during production by adjusting nutrient and/or water regimes is receiving increased attention as a way to produce sturdy plants with a high level of photosynthetic reserves that are capable of quick establishment and growth in the landscape (Dufault, 1994; Latimer, 1990).

Pre-transplant conditioning has been defined as the process of nutritionally conditioning seedlings during the greenhouse production phase to predispose the seedlings to tolerate transplant stresses better, recover quickly from transplant shock and enhance earlier yields (Dufault, 1986). Cucumis grown with increasing rates of nitrogen in the

greenhouse had a greater occurrence of transplant shock than those conditioned with low nitrogen (Dufault, 1986). Lower nitrogen levels were shown to promote root growth over shoot growth in many crops, thus increasing their root:shoot ratio (Masson et al., 1990, 1991; Tremblay and Senecal, 1988). Transplants with well developed root systems recovered more quickly from transplant shock (Weston and Zandstra, 1986). Conditioning seedlings with low pre-transplant nutritional conditioning before field planting has been shown to be more beneficial than hardening with total nutrient withdrawal (Armitage, 1986; Garton and Widders, 1990; Nell et al., 1994).

Eakes et al. (1991a) defined moisture stress conditioning as the controlled exposure of plants to moisture deficits during production. Moisture stress conditioning during production was reported to improve the growth and/or yield of several agronomic crops when exposed to future moisture stress (Ackerson and Hebert, 1981; Brown et al., 1976; Gupta and Berkowitz, 1987; Matthews and Boyer, 1984). Petunia grown under a low-frequency irrigation regime exhibited improved postproduction quality (Armitage and Kowalski (1983b). Moisture stress conditioning of both Salvia (Eakes et al. 1991a) and Catharanthus (Virk and Singh, 1990) were found to improve their physiological tolerance to lower water potentials due to osmotic adjustment, but neither of these studies evaluated the plants' postproduction performance in landscape beds.

Chemical growth retardants are commonly used in the commercial production of bedding plants to produce plants that are compact, making them easier to ship and more attractive to the consumer. However, the carry over effect of these growth retardants into a landscape setting has only recently started to be a concern. Latimer (1991) showed that

Zinnia, Impatiens and Tagetes all experienced reduced landscape establishment and growth to various degrees from the three growth retardants studied, paclobutrazol, daminozide and ancymidol. Tagetes growth continued to be reduced by drench treatments in the greenhouse of paclobutrazol for up to 138 days after treatment (Keever and Cox, 1989). Plants where paclobutrazol was foliar applied did not experience reductions in growth for as long. Residual effects may be more important with the use of the new triazole compounds, such as paclobutrazol and uniconazole, which appear to be active in plants for longer than the older growth retardants (Davis et al., 1988). Chemical growth retardants have also been shown to improve the stress tolerance of treated bedding plants in the landscape by modifying plant anatomy and/or physiology (Armitage et al., 1981; Cathey, 1964; Davis and Andersen, 1989; Seeley, 1985).

The purpose of this research was to evaluate the effect of pretransplant- nutritional-conditioning, moisture-stress-conditioning and a chemical growth retardant (uniconazole) on the subsequent establishment and growth of Catharanthus in a landscape field setting with two slow-release fertilizer rates. Uniconazole translocates exclusively in the plant xylem (Dalziel and Lawrence, 1984). It reduces plant growth by inhibiting the first three steps of ent-kaurene oxidation, blocking the oxidation of kaurene to kaurenoic acid and thus inhibiting gibberellin biosynthesis (Rademacher et al., 1984). The goal of the first experiment was to determine the proper time to apply and concentration of uniconazole so that plants leave the greenhouse with an acceptable size and appearance and yet will not suffer any reductions in growth once they are planted in a landscape setting. Another goal of this experiment was to determine if fertilizer in the landscape can be used to help

overcome any potential residual effects from a greenhouse-applied growth retardant. The goal of the second experiment was to determine if producing Catharanthus under lower than commercially standard nitrogen levels would have any negative effects on greenhouse growth and/or landscape performance under two different slow-release fertilizer rates. Also, the second experiment was designed to compare the effectiveness of moisture stress conditioning versus a commercially used plant growth retardant in producing a compact plant that would also perform well in the landscape.

## Materials and Methods

Experiment 1. This experiment was designed to investigate the effects of uniconazole greenhouse application time and concentration on the subsequent landscape growth of Catharanthus roseus 'Cooler Peppermint'. Seedlings were grown in 390 plug trays were shipped from Natural Beauty Greenhouses in Apopka, Florida, to Gainesville, Florida on 2 April 1993. The 18 mm x 18 mm plugs were transplanted into 10-cm diameter by 8-cm deep plastic azalea containers using Vegro Clay Mix (Verlite Co., Tampa, FL) medium on 3 April. All plants were thoroughly watered and spaced on wire mesh benches in a Lexan-covered greenhouse. Since some plugs contained multiple plants, all but one plant per container were basally cut with a pair of scissors. Plants were maintained well-watered as necessary throughout the experiment and never experienced wilting conditions. Liquid fertilizer derived from 20% N, 4.3% P, 16.6% K was applied at a concentration of 150 ppm N during each watering throughout the greenhouse portion of the experiment.

On 26 April, all plants were placed into a randomized, complete block design with five plants per experimental unit and three replications. The experiment was a 2 x 5 x 2 factorial with 2 uniconazole application times, 5 uniconazole concentrations and 2 landscape fertilizer rates. The two times that uniconazole was applied were "week 3" (applied 3 weeks after plugs were transplanted) or "week 5" (applied 5 weeks after plugs were transplanted). The five concentrations of uniconazole were "control" (0 mg·liter$^{-1}$), "low" (1 mg·liter$^{-1}$), "medium" (2 mg·liter$^{-1}$), "high" (4 mg·liter$^{-1}$) or "very high" (8 mg·liter$^{-1}$). The two landscape fertilizer rates were "low" (0.38 lbs of N/1,000 ft$^2$ with 0.25 lbs of N supplied per month) or "high" (1.5 lb of N/1,000 ft$^2$ with 1.0 lb of N supplied per month). The fertilizer was Nutricote 14-14-14 type 70 (14% N, 3.0% P, 11.6% K) and was incorporated into the top 6 inches of soil with a rototiller.

Uniconazole was applied at the volume of 2 quarts solution per 100 ft$^2$. The greenhouse production phase of the experiment was terminated on 12 May. At this time plant height, plant width and shoot dry weight were determined. Plant height was measured from the level of the medium to the top of the plant. Two plant width measurements were taken perpendicular to each other and averaged to determine average plant width. The average plant width was added to the plant height and divided by two to calculate average plant size. Shoot dry weight was determined by harvesting all plant tissue above the medium level, drying in a 70° C drying oven for 7 days and weighing.

Soil in landscape beds had a sand texture, a pH of 6.5, a very high level of available phosphorous (120 ppm+ P) and a medium level of available potassium (48 ppm K). The plants were planted 12-inches apart on 14 May. Plants were watered as needed to avoid

visible wilting with a drip irrigation system for the duration of the landscape portion of the study. Watering occurred on a daily or every-other-day basis.

Height and two widths were measured on each plant on 15 May, 31 May, 12 June and 23 June. Average plant width and plant size were determined for each date. The landscape portion of the study was terminated on 29 June at which time all tissue above the soil line was harvested, placed in a drying oven at 70° C for one week and weighed to determine shoot dry weight. Change in plant height, width and size was calculated for each two-week time interval and for the entire time (6 weeks) in the landscape. All data were subjected to analysis of variance and regression analysis.

Experiment 2. This experiment was designed to investigate the effects of production fertility, production moisture-stress-conditioning and greenhouse applied uniconazole on the subsequent landscape performance of Catharanthus. Seedlings were obtained as described previously on 6 June 1996 and transplanted into 10-cm diameter by 8-cm deep plastic azalea containers using Vegro Clay Mix (Verlite Co., Tampa, FL) medium on 7 June. Plants were thoroughly watered and spaced on wire mesh benches in a Lexan-covered greenhouse and pruned to one plant per container. Plants were maintained well-watered and never experienced wilting conditions during the subsequent 2-week period.

On 21 June, all plants were placed into a randomized, complete block design with five plants per experimental unit and three replications. The experiment was a 2 x 3 x 2 factorial with 2 greenhouse fertilizer concentrations, 3 water regimes and 2 landscape fertilizer rates. The two greenhouse fertilizer concentrations were "low" (50 ppm N) and "high" (150 ppm N). Liquid fertilizer derived from 20% N, 4.3% P, 16.6% K was used

for both fertilizer concentrations during the greenhouse portion of the experiment. The three water regimes in the production phase were "WW" (plants were maintained well watered throughout the entire experiment), "W+1" (plants were allowed to wilt for one day before being watered again) and "WW+Uniconazole" (plants were maintained well watered and sprayed with 2 $mg \cdot liter^{-1}$ uniconazole on 28 June). The two landscape fertilizer rates were "low" (0.38 lbs of N/1000 $ft^2$ with 0.25 lbs. of N supplied per month) or "high" (1.5 lbs of N/1000 $ft^2$ with 1.0 lb of N supplied per month). The fertilizer was Osmocote 14-14-14 (90 day release time) and was incorporated into the top 6 inches of soil with a rototiller.

The greenhouse production phase of the experiment was terminated on 26 July. At this time plant height, width and size were determined. Plant size and mass were measured as described in Experiment 1.

The plants were installed on 28 July in the same landscape bed using the same procedures as described for Experiment 1. Height and two widths were measured on each plant on 28 July, 12 Aug., 26 Aug. and 9 Sept. Average plant width and plant size were determined for each date. The landscape portion of the study was terminated on 10 Sept. at which time all tissue above the soil line was harvested, placed in a drying oven at 70° C for 1 week and weighed to determine shoot dry weight. Change in plant height, width and size was calculated for each two-week time interval and for the entire time (6 weeks) in the landscape. All data were subjected to analysis of variance and Tukey mean separation.

## Results and Discussion

### Experiment 1- Greenhouse Growth

There was a significant interaction between uniconazole application time and uniconazole concentration in their effects on plant height, width and size at the end of the greenhouse production phase (P=0.0001). For application at week 3, increasing concentrations of uniconazole were found to decrease final greenhouse height (Figure 5-1), width (Figure 5-2), size (Figure 5-3), total leaf area (Figure 5-4) and shoot dry weight (Figure 5-5). Regression analysis gave the best fit for all of the above growth parameters with a linear model (P=0.0001). I think that plants treated with uniconazole between 2 and 4 $mg \cdot liter^{-1}$ possessed the most desirable size and proportion for marketing. For application at week 5, increasing concentrations of uniconazole produced no significant differences in plant height (Figure 5-1), width (Figure 5-2) or size (Figure 5-3) at the end of greenhouse production. That no difference in plant growth occurred for this application time was not surprising for the growth retardant was only applied 2 days before measurements were taken.

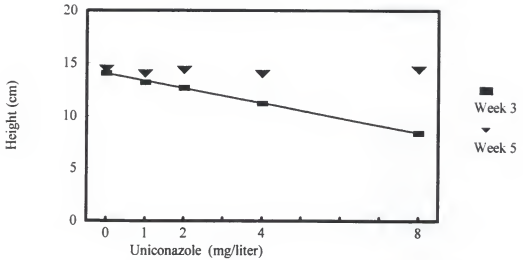


Figure 5-1 Effect of uniconazole application time and concentration on final plant height in the greenhouse. Week 3: y=14.04 -0.71x, r=.74; Week 5: n.s.

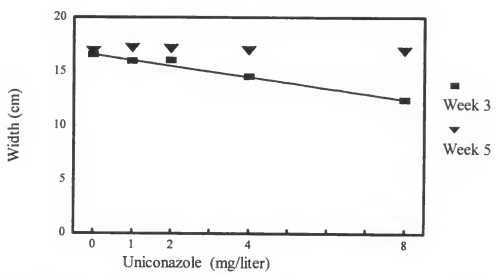


Figure 5-2 Effect of uniconazole application time and concentration on final plant width in the greenhouse. Week 3: y=16.71 -0.53x, r=.76; Week 5: n.s.

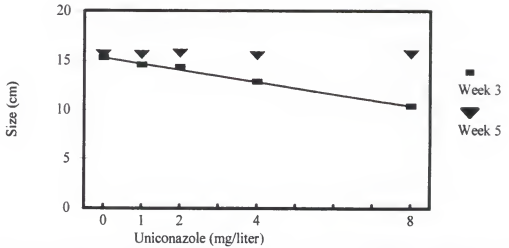


Figure 5-3 Effect of uniconazole application time and concentration on final plant size in the greenhouse. Week 3: y=15.38 -0.62x, r=.78; Week 5: n.s.

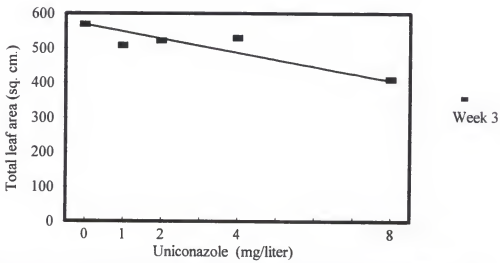


Figure 5-4 Effect of uniconazole concentration at week 3 on final total leaf area in the greenhouse. Week 3: y=557 -17x, r=.81.

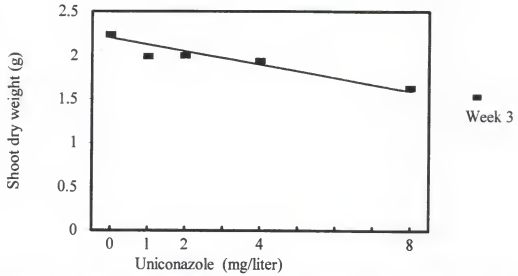


Figure 5-5 Effect of uniconazole concentration at time 3 on final shoot dry weight in the greenhouse. Week 3: y=2.16 -0.07x, r=.36.

Experiment 1 - Landscape Growth

A three-way interaction between effects of uniconazole time, concentration and landscape fertilizer rate did not exist for change in plant height, width or size during the first 2 weeks in the field (Table 5-1). There was a significant interaction between effects of time of uniconazole application and concentration on changes in plant height, width and size (Table 5-1). Regression analysis gave the best fit for all of the above growth parameters with a linear model. When uniconazole was applied at 3 weeks in the greenhouse, increasing concentration resulted in greater height growth (Figure 5-6). When uniconazole was applied at 5 weeks in the greenhouse, increasing concentration resulted in less height growth. Uniconazole concentration did not affect change in plant width for week 3, although increasing concentrations resulted in smaller changes in plant width for week 5 (Figure 5-7). Change in size increased as uniconazole concentration

increased for week 3 and decreased as concentration increased for week 5 (Figure 5-8). Plants grown at the high field fertilizer rate had greater increases in plant widths (8.39 versus 6.93 cm) and size (5.81 versus 5.08 cm), but had no effect on height growth (3.23 versus 3.24 cm) between 0 and 2 weeks in the field.

Table 5-1 Significance of uniconazole application time, concentration and landscape fertilizer rate on change in plant height, width and size of Catharanthus roseus 'Cooler Peppermint' between 0 and 2 weeks in the field. Experiment 1.

| | Change in: | | |
|---|---|---|---|
| | Height (cm) | Width (cm) | Size (cm) |
| Effect | Significant at P = | | |
| Fertilizer | 0.9460 | 0.0072 | 0.0471 |
| Time | 0.0001 | 0.0001 | 0.0001 |
| Fertilizer*Time | 0.8344 | 0.4696 | 0.5304 |
| Concentration | 0.0502 | 0.0269 | 0.0654 |
| Time* Concentration | 0.0021 | 0.0045 | 0.0001 |
| Fertilizer* Concentration | 0.6136 | 0.3644 | 0.4609 |
| Fertilizer*Time* Concentration | 0.9356 | 0.4710 | 0.7447 |

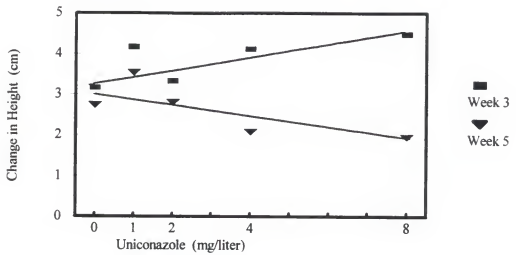


Figure 5-6 Effect of uniconazole application time and concentration on change in plant height after 2 weeks in the field. Week 3: y=3.49 +0.13x; Week 5: y=3.09 -0.16x, r=.47.

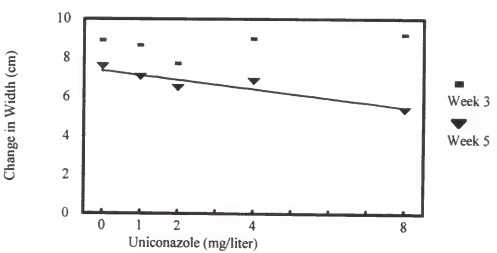


Figure 5-7 Effect of uniconazole application time and concentration on change in plant width after 2 weeks in the field. Week 3: n.s.; Week 5: y=7.38 -0.25x, r=.63.

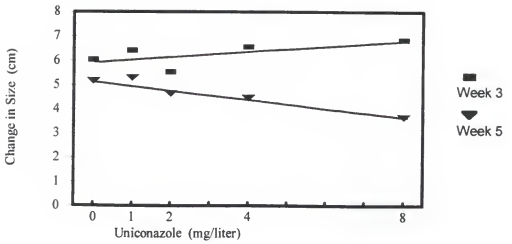


Figure 5-8 Effect of uniconazole time and concentration on change in plant size after 2 weeks in the field. Week 3: 5.97 +0.10x; Week 5: y=5.24 -0.20x, r=.54.

There was a significant interaction between uniconazole application time and concentration for change in plant height between weeks two and four in the field (P=0.0044). Regression analysis gave the best fit with a linear model. Change in height increased as uniconazole concentration increased for week 3 (P=0.0011) and decreased as concentration increased for week 5 (P=0.0021)(Figure 5-9). This effect was the same as reported for the first 2 weeks in the field. No interaction between time and concentration existed for change in plant width or size. Neither time nor concentration themselves affected change in plant width or size.

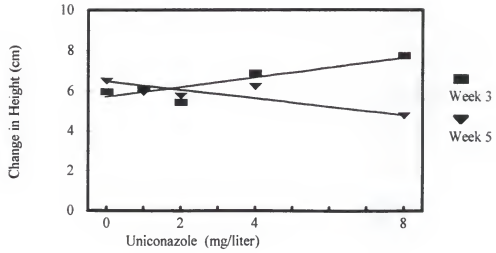


Figure 5-9 Effect of uniconazole application time and concentration on change in plant height between 2 and 4 weeks in the field. Week 3: y=5.68 +0.25x; Week 5: y=6.36 - 0.18x, r=.49.

Neither uniconazole application time nor concentration was found to have an effect on change in plant height between weeks four and six in the field. However, there was a significant interaction between time and concentration for change in plant width (P=0.0051) and change in plant size (P=0.0384). Regression analysis gave the best fit with a quadratic model. Increasing concentrations of uniconazole up to 4 $mg \cdot liter^{-1}$ applied at week 3 caused greater increases in plant width (P=0.0012)(Figure 5-10) and size (P=0.0091)(Figure 5-11). Uniconazole concentration had no effect on increases in plant width or size when applied at week 5. No differences in growth between four and six weeks in the field were attributed to field fertilizer rates

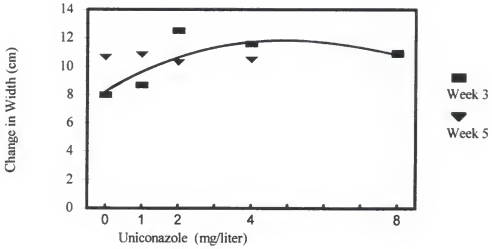


Figure 5-10 Effect of uniconazole applicatin time and concentration on change in plant width between 4 and 6 weeks in the field. Week 3: $y=7.93 +1.84x -0.19x^2$, r=.44; Week 5: n.s.

From planting to 6 weeks, there was not a significant three-way interaction among uniconazole application time and concentration and landscape fertilizer rate for change in plant height, width or size (Table 5-2). There was a significant interaction between uniconazole application time and concentration for change in plant height, width and size. Regression analysis gave the best fit for all of the above growth parameters. For application of uniconazole at week 3, increasing concentrations of uniconazole resulted in greater changes in plant height (linear model)(Figure 5-12), but for application at week 5,

uniconazole concentration did not have any affect on change in plant height (Figure 5-12). Increasing concentrations of uniconazole up to 4 mg·liter$^{-1}$ produced greater changes in plant width (quadratic model) for application at week 3 while height growth decreased as concentration increased for week 5 (linear model)(Figure 5-13). Increasing concentrations up to 4 mg·liter$^{-1}$ also produced greater changes in plant size (quadratic model) for week 3 and smaller changes for week 5 (linear model)(Figure 5-14). Time of application or concentration of uniconazole did not cause any differences in shoot dry weights after 6 weeks in the field (45 g +/- 1.2). No differences in growth over the 6 weeks in the field were attributed to field fertilizer rates.

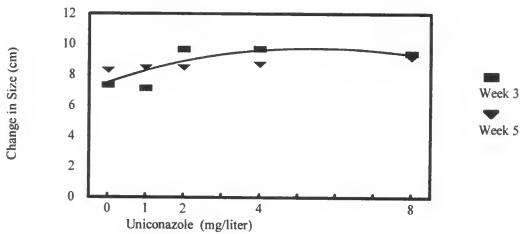


Figure 5-11 Effect of uniconazole application time and concentration on change in plant size between 4 and 6 weeks in the field. Week 3: 7.02 +1.13x -0.10$x^2$ , r=.45; Week 5: n.s.

Table 5-2 Significance of uniconazole application time, concentration and landscape fertilizer rate on change in plant height, width and size of Catharanthus roseus 'Cooler Peppermint' between 0 and 6 weeks in the field. Experiment 1.

| | Change in: | | |
|---|---|---|---|
| | Height (cm) | Width (cm) | Size (cm) |
| Effect | Significant at P = | | |
| Fertilizer | 0.4170 | 0.0510 | 0.0919 |
| Time | 0.0001 | 0.0002 | 0.0001 |
| Fertilizer*Time | 0.0564 | 0.8462 | 0.2424 |
| Concentration | 0.0859 | 0.0239 | 0.0450 |
| Time* Concentration | 0.0005 | 0.0045 | 0.0001 |
| Fertilizer* Concentration | 0.1835 | 0.5162 | 0.2306 |
| Fertilizer*Time* Concentration | 0.5032 | 0.7134 | 0.4343 |

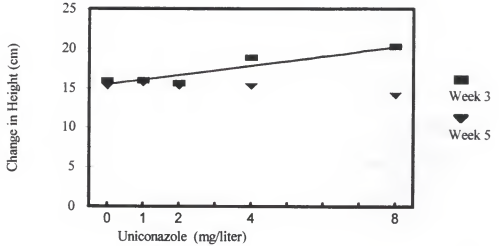


Figure 5-12 Effect of uniconazole application time and concentration on change in plant height during 6 weeks in the field. Week 3: y=15.45 +0.62x, r=.50; Week 5: n.s.

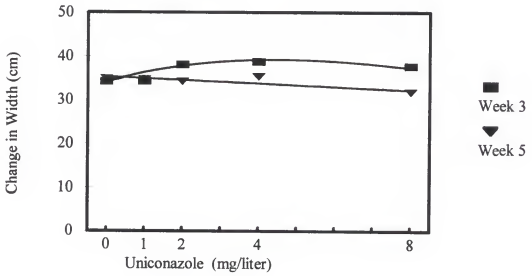


Figure 5-13 Effect of uniconazole application time and concentration on change in plant width during 6 weeks in the field. Week 3: $y=33.68 +2.08x -0.20x^2$ ; Week 5: y=35.24 - 0.36x, r=.48.

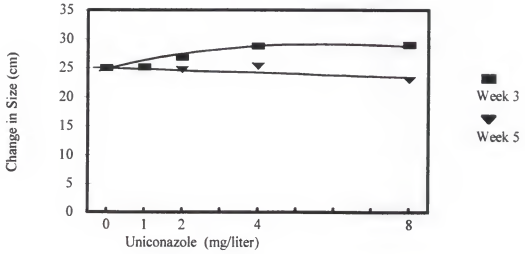


Figure 5-14 Effect of uniconazole application time and concentration on change in plant size during 6 weeks in the field. Time 3: $24.53 + 1.38x - 0.10x^2$; Time 5: $y=25.39 - 0.26x$. $r=.54$.

Uniconazole concentration produced a significant effect on overall plant size between 0 and 6 weeks in the field (P=0.0045). All concentrations resulted in plants of equal overall size with the exception of the highest concentration which produced smaller plants (Table 5-3). Since the plants from the various uniconazole concentrations applied at week 3 were not all the same size when they were planted in the field (Figure 5-3), looking at the final overall size after 6 weeks would not give as accurate picture of what growth actually occurred in the field as looking at changes in plants size. The plants receiving no uniconazole were actually planted into the field in this study at a larger size than they would normally be in a commercial situation. Since the goal of bedding plant establishment in the field is to have the plants fill in and touch as quickly as possible,

uniconazole should be applied in the greenhouse 3 weeks after plug transplanting at a concentration between 2 and 4 mg liter$^{-1}$.

Table 5-3 Effect of uniconazole concentration on the overall plant size of Catharanthus roseus 'Cooler Peppermint' between 0 and 6 weeks in the field.

| Uniconazole concentration (mg liter$^{-1}$) | Overall plant size (cm)* |
|---|---|
| 0 | 42.7 a |
| 1 | 42.0 a |
| 2 | 42.6 a |
| 4 | 42.9 a |
| 8 | 40.5 b |

* Tukey Studentized Range (HSD) Test: means followed by the same letter are not different at P=0.05.

An application of uniconazole between 2 and 4 mg·liter$^{-1}$ sprayed on Catharanthus in 10 cm containers three weeks after plugs were transplanted was an effective means of producing an attractive, compact, well-proportioned flowering plant that would be easy to ship and attractive to the consumer. The lower concentration resulted in plants that were too large for efficient shipping while the higher concentration resulted in plants that were too compact to be aesthetically appealing to the consumer. This finding agrees with earlier work done by Barrett and Nell (1987) with uniconazole on Catharanthus.

The time of uniconazole application in the greenhouse was found to have a great effect on the subsequent landscape growth. For most of the bedding plants and chemical growth retardants studied by Latimer (1991) it took 5 to 7 weeks in the landscape for treated plants to equal the size of untreated plants. Growth retardants in Latimer's study were

applied to relatively young seedlings in cell packs. Paclobutrazol, another triazole compound similar to uniconazole, continued to reduce the growth of Tagetes in the landscape 138 days after a greenhouse drench treatment while spray treatments were no longer effective at that time (Keever and Cox, 1989). Rather than inhibiting the establishment and growth of Catharanthus in the landscape, foliar applying uniconazole 3 weeks after transplanting plugs in the greenhouse actually was found to enhance field growth. The application of uniconazole at time 5 resulted in less field growth during the entire 6 weeks when compared to application time 3.

Plants treated with chemical growth retardants have been shown to display increased resistance to environmental stresses, including drought (Asare-Boamah et al., 1988; Barrett and Nell; 1982; Cathey, 1964; Gao et al.; 1988; Morandi et al., 1984; Swietlik and Miller, 1983). Other researchers have found that growth retardants reduced total plant water use, but did not affect transpiration per unit leaf area (Barrett and Nell, 1981, 1982; Bryan, 1989; Steinberg et al., 1991; Wample and Culver, 1983). Rather, the reduced water use was due to a reduction in total leaf area. Plaut et al. (1964) did report that chlormequat reduced transpiration rate per unit leaf area in Phaseolus. Lycopersicum treated with chlormequat had lower tranpiration due to reduced stomatal aperture (Mishra and Pradhan, 1968). Hibiscus treated with uniconazole had smaller leaf area and individual leaves had a lower stomatal density, conductance and tranpiration rate (Steinberg et al, 1991). The smaller total leaf areas of Catharanthus treated with uniconazole at week 3 may have given them an advantage in the field by reducing whole plant transpiration.

Chemical growth retardants have also been shown to create a greater root:shoot ratio in plants (McConnell and Struckmeyer, 1970). A greater root:shoot ratio in Catharanthus treated with uniconazole would have improved their water relations in the field by having fewer shoots to transpire water and by having more roots to absorb water relative to the untreated controls.

Studies have shown that shoot fresh and dry weights of plants treated with growth retardants were significantly higher when grown under water stressed conditions (Barrett and Nell, 1982; Halevy and Kessler, 1963; Lee et al, 1974; Pill et al., 1979; Plaut and Halevy, 1966). That all of the Catharanthus had statistically the same shoot dry weights after six weeks of growth in the field, even though plants from each uniconazole treatment from week 3 started in the field with great differences in shoot dry weight, confirmed this effect of growth retardants on subsequent plant growth. Therefore, if uniconazole is applied 3 weeks before the end of production rather than at the very end, the negative carryover effects in the field can be eliminated with Catharanthus.

The plants in this study were maintained in the field under well watered conditions. Wilting rarely occurred and was only allowed to persist for a couple of hours. Even under well watered conditions, some water stress most likely occurred that would affect stomatal closure (Bates and Hall, 1981; Blackman and Davies, 1985; Davies et al, 1980; Gollan et al., 1986; Gowing et al., 1990; Kuppers et al., 1988; Passioura, 1988; Saab and Sharp, 1989; Zhang and Davies, 1989, 1990a; Zhang et al., 1987). Catharanthus plants treated with uniconazole at week 3 were apparently able to overcome these periods of even brief

moisture stress in the field, as evidenced by their increased growth relative to the untreated controls during the six week period in the field.

Applying uniconazole at the very end of the greenhouse production cycle was found to inhibit the establishment and growth of Catharanthus in the landscape, particularly during the first four weeks. It appears that the efficacy of uniconazole on Catharanthus at the concentrations used in this study is between three and four weeks. Thus, if a grower wants to produce Catharanthus that is both compact and will quickly establish in the landscape, uniconazole should be foliar applied three to four weeks before shipping at a concentration between 2 and 4 $mg \cdot liter^{-1}$. The exact concentration would depend on an individual grower's production environment and targeted finished plant size.

Experiment 2 - Greenhouse Growth

There was a significant interaction ($P=0.0009$) between greenhouse fertilizer concentration and water regime on plant height at the end of production. Within each water treatment, fertilizer rate did not produce a difference in height (Table 5-4). Well-watered plants were the tallest, with no differences between W+1 plants or well-watered plants treated with uniconazole (Table 5-4). There was a greater difference between WW and the other two water regimes for the low fertilizer than with the high fertilizer. No interaction between greenhouse fertilizer concentration and water regime was discovered for plant width or size at the end of production. Plants receiving more fertilizer were wider and larger (Table 5-4). Well watered plants were the widest, followed by well watered plants treated with uniconazole and finally W+1 plants (Table 5-4). A similar

pattern was present for final plant size (Table 5-4). The differences in plant size between treatments were due to differences in plant width.

Table 5-4 Effects of two greenhouse fertilizer concentrations and three water regimes on plant height, width and size of Catharanthus roseus 'Cooler Peppermint' after 6 weeks of production.

| Height (cm)* | | |
|---|---|---|
| Water regime^ | Low Fertilizer | High Fertilizer |
| WW | 28.6 a | 27.3 a |
| WW+Uniconazole | 18.2 b | 19.2 b |
| W+1 | 18.6 b | 19.6 b |

* Tukey Studentized Range (HSD) Test: means within table followed by the same letter (in and between columns) are not different at P=0.05.

| | Width (cm)* | | Width (cm)* |
|---|---|---|---|
| Water regime^ | | Fertilizer | |
| WW | 29.9 a | Low | 20.8 a |
| WW+Uniconazole | 20.5 b | High | 24.9 b |
| W+1 | 18.2 c | | |

| | Size (cm)* | | Size (cm)* |
|---|---|---|---|
| Water regime^ | | Fertilizer | |
| WW | 28.9 a | Low | 21.3 a |
| WW+Uniconazole | 19.6 b | High | 22.4 b |
| W+1 | 18.6 c | | |

* Tukey Studentized Range (HSD) Test: means within each table followed by the same letter (in columns) are not different at P=0.05.

^ Water regime: well watered (WW); well watered with 2 mg·liter$^{-1}$ uniconazole foliar applied 3 weeks after transplanting (WW+Uniconazole); wilt maintained for 1 day prior to watering (W+1)

This study showed that treating well-watered Catharanthus with 2 mg·liter$^{-1}$ uniconazole and allowing plants to wilt for 1 day between waterings produced plants were significantly different in width and size, but the same height. Even though there were differences in width and size, these two treatments were both effective in producing compact plants of desirable marketing size. Therefore, water stress could be a viable substitute for chemcial growth retardants as a means of controlling Catharanthus size in the greenhouse.

Experiment 2 - Landscape Growth

Between 0 and 2 weeks in the field, there were no significant interactions among effects of greenhouse fertilizer, greenhouse water regime or landscape fertilizer on change in plant height (Table 5-5). The only variable to significantly affect landscape plant height was greenhouse water regime where WW+Uniconazole plants grew about one-half as much as WW and W+1 plants.

Table 5-5 Significance of greenhouse fertilizer concentration, greenhouse water regime and landscape fertilizer rate on change in plant height, width and size of Catharanthus roseus 'Cooler Peppermint' between 0 and 2 weeks in the field. Experiment 2.

| | Change in: | | |
|---|---|---|---|
| | Height (cm) | Width (cm) | Size (cm) |
| Effect | Significant at P = | | |
| Greenhouse fertilizer | 0.0585 | 0.0007 | 0.0670 |
| Greenhouse water regime | 0.0001 | 0.0001 | 0.0001 |
| Greenhouse fertilizer*Water regime | 0.9846 | 0.2422 | 0.4071 |
| Landscape fertilizer | 0.2342 | 0.0034 | 0.0017 |
| Greenhouse fertilizer* Landscape fertilizer | 0.2225 | 0.0052 | 0.0024 |
| Water regime* Landscape fertilizer | 0.6432 | 0.1620 | 0.1097 |
| Greenhouse fertilizer*Water regime*Landscape fertilizer | 0.3207 | 0.0088 | 0.0030 |

A significant three-way interaction was found for change in width between 0 and 2 weeks in the field (Table 5-5). The only difference due to greenhouse fertilizer concentration was for WW plants that received the low landscape fertilizer rate where the high greenhouse fertilizer rate caused more growth than the low greenhouse fertilizer concentration (Table 5-6). For the high landscape fertilizer rate there was a greater

change in plant width for W+1 plants that received the high greenhouse fertilizer concentration (Table 5-6). WW and WW+Uniconazole plants that received the low greenhouse fertilizer rate grew wider with the high landscape fertilizer rate (Table 5-6). Regardless of the greenhouse fertilizer and landscape fertilizer treatments, there was no difference in change in width between 0 and 2 weeks in the field between the WW+Uniconazole and W+1 plants (Table 5-6). Both treatments did grow significantly more in width than the WW plants, except for the high greenhouse x low landscape fertilizer treatment where the change in width was the same (Table 5-6).

Table 5-6 Effect of two greenhouse fertilizer concentrations, three greenhouse water regimes and two landscape fertilizer rates on the change in plant width of Catharanthus roseus 'Cooler Peppermint' between 0 and 2 weeks in the field.

| | Change in plant width (cm)* | | | |
|---|---|---|---|---|
| | Low greenhouse fertilizer | | High greenhouse fertilizer | |
| Water regime^ | Low landscape fertilizer | High landscape fertilizer | Low landscape fertilizer | High landscape fertilizer |
| WW | 0.07 f | 2.17 de | 3.78 bcde | 2.01 ef |
| WW+ Uniconazole | 3.86 bcde | 6.30 a | 5.63 ab | 5.35 abc |
| W+1 | 3.43 cde | 4.65 abc | 4.16 bcd | 6.36 a |

* Tukey Studentized Range (HSD) Test: means within table followed by the same letter (in and between columns) are not different at P=0.05.
^ Water regime: well watered (WW); well watered with 2 mg·liter$^{-1}$ uniconazole foliar applied 3 weeks after transplanting (WW+Uniconazole); wilt maintained for 1 day prior to watering (W+1)

A significant three-way interaction was also found for change in plant size between 0 and 2 weeks in the field (P=0.0030). The only difference due to greenhouse fertilizer concentration was for WW plants that received the low landscape fertilizer rate

(Table 5-7). Landscape fertilizer rate did not produce any changes in plant size between 0 and2 weeks in the field for any of the greenhouse fertilizer x water regime treatments. The only difference in change in plant size due to greenhouse water regime was between W+1 and WW plants for the high greenhouse fertilizer x high landscape fertilizer treatment and the low greenhouse fertilizer x low landscape fertilizer treatment, where W+1 plants were larger (Table 5-7).

Table 5-7 Effect of two greenhouse fertilizer concentrations, three greenhouse water regimes and two landscape fertilizer rates on the change in plant size of Catharanthus roseus 'Cooler Peppermint' between 0 and 2 weeks in the field.

| | Change in plant size (cm)* | | | |
|---|---|---|---|---|
| | Low greenhouse fertilizer | | High greenhouse fertilizer | |
| Water regime^ | Low landscape fertilizer | High landscape fertilizer | Low landscape fertilizer | High landscape fertilizer |
| WW | 0.78 d | 2.19 bcd | 2.73 abc | 1.55 cd |
| WW+ Uniconazole | 2.26 bcd | 3.71 ab | 3.10 abc | 2.90 abc |
| W+1 | 2.60 abc | 3.42 ab | 2.70 abc | 4.14 a |

* Tukey Studentized Range (HSD) Test: means within table followed by the same letter (in and between columns) are not different at P=0.05.

^ Water regime: well watered (WW); well watered with 2 mg·liter$^{-1}$ uniconazole foliar applied 3 weeks after transplanting (WW+Uniconazole); wilt maintained for 1 day prior to watering (W+1)

There were no significant interactions between greenhouse fertilizer, greenhouse water regime or landscape fertilizer on change in plant height between 0 and 6 weeks in the field (Table 5-8). The only variable to show a significant effect was the landscape fertilizer rate where plants receiving the high rate grew one-third more in height than those plants receiving the low rate.

Table 5-8 Significance of greenhouse fertilizer concentration, greenhouse water regime and landscape fertilizer rate on change in plant height, width and size of Catharanthus roseus 'Cooler Peppermint' between 0 and 6 weeks in the field. Experiment 2.

| | Change in: | | |
|---|---|---|---|
| | Height (cm) | Width (cm) | Size (cm) |
| Effect | Significant at P = | | |
| Greenhouse fertilizer | 0.5954 | 0.6232 | 0.0715 |
| Greenhouse water regime | 0.2082 | 0.0001 | 0.5048 |
| Greenhouse fertilizer*Water regime | 0.2934 | 0.8475 | 0.8890 |
| Landscape fertilizer | 0.0001 | 0.0001 | 0.0001 |
| Greenhouse fertilizer* Landscape fertilizer | 0.2222 | 0.0001 | 0.0001 |
| Water regime* Landscape fertilizer | 0.8633 | 0.0250 | 0.2232 |
| Greenhouse fertilizer*Water regime*Landscape fertilizer | 0.2539 | 0.0238 | 0.0125 |

A significant three-way interaction was found for change in width between 0 and 6 weeks in the field (Table 5-8). The only effect due to greenhouse fertilizer concentration was for WW plants. The high greenhouse fertilizer rate produced wider plants with the low landscape fertilizer rate and narrower plants with the high landscape fertilizer rate (Table 5-8). The high landscape fertilizer rate resulted in greater changes in width between 0 and 6 weeks in the field for every greenhouse fertilizer x water regime

treatment except for WW plants receiving the high greenhouse fertilizer concentration, where no difference was found between the two landscape fertilizer rates (Table 5-9). Regardless of the greenhouse fertilizer*landscape fertilizer treatment, there was no difference in change in plant width between 0 and 6 weeks in the field between the WW+Uniconazole and W+1 plants (Table 5-9). Both treatments did grow significantly more in width than the WW plants, except for the high greenhouse x low landscape fertilizer treatment where the change in width was the same (Table 5-9).

Table 5-9 Effect of two greenhouse fertilizer concentrations, three greenhouse water regimes and two landscape fertilizer rates on the change in plant width of Catharanthus roseus 'Cooler Peppermint' between 0 and 6 weeks in the field.

| | Change in plant width (cm)* | | | |
|---|---|---|---|---|
| | Low greenhouse fertilizer | | High greenhouse fertilizer | |
| Water regime^ | Low landscape fertilizer | High landscape fertilizer | Low landscape fertilizer | High landscape fertilizer |
| WW | 1.37 f | 11.80 cd | 6.13 e | 7.12 e |
| WW+ Uniconazole | 6.39 e | 17.10 ab | 8.48 de | 13.60 bc |
| W+1 | 7.76 de | 18.10 a | 8.56 de | 17.10 ab |

* Tukey Studentized Range (HSD) Test: means within table followed by the same letter (in and between columns) are not different at P=0.05.
^ Water regime: well watered (WW); well watered with 2 mg·liter$^{-1}$ uniconazole foliar applied 3 weeks after transplanting (WW+Uniconazole); wilt maintained for 1 day prior to watering (W+1)

A significant three-way interaction was also found for change in plant size between 0 and 6 weeks in the field (Table 5-7). Greenhouse fertilizer concentration did not have an effect on change in plant size after 6 weeks. The high landscape fertilizer rate produced

greater changes in plant size between 0 and 6 weeks in the field for all of the greenhouse fertilizer x water regime treatments except for the WW plants receiving the high greenhouse fertilizer concentration, where change in plant size was the same for both landscape fertilizer rates (Table 5-10). No difference in change in plant size was found between the WW+Uniconazole and W+1 plants for any of the greenhouse fertilizer x landscape fertilizer treatments (Table 5-10). W+1 plants grew more than WW plants except for the high greenhouse fertilizer x low landscape fertilizer treatment (Table 5-10). WW+Uniconazole plants grew more than the WW plants only when receiving the high landscape fertilizer rate (Table 5-10).

Table 5-10 Effect of two greenhouse fertilizer concentrations, three greenhouse water regimes and two landscape fertilizer rates on the change in plant size of Catharanthus roseus 'Cooler Peppermint' during 6 weeks in the field.

| | Change in plant size (cm)* | | | |
|---|---|---|---|---|
| | Low greenhouse fertilizer | | High greenhouse fertilizer | |
| Water regime^ | Low landscape fertilizer | High landscape fertilizer | Low landscape fertilizer | High landscape fertilizer |
| WW | 3.51 c | 11.00 b | 6.10 bc | 7.58 b |
| WW+ Uniconazole | 6.31 bc | 13.40 a | 7.92 b | 11.70 a |
| W+1 | 7.56 b | 14.00 a | 7.61 b | 13.40 a |

* Tukey Studentized Range (HSD) Test: means within table followed by the same letter (in and between columns) are not different at P=0.05.

^ Water regime: well watered (WW); well watered with 2 mg·liter$^{-1}$ uniconazole foliar applied 3 weeks after transplanting (WW+Uniconazole); wilt maintained for 1 day prior to watering (W+1)

There was a significant three-way interaction among the effects of greenhouse fertilizer concentration, greenhouse water regime and field fertilizer rate on overall plant size during 6 weeks in the field (P=0.0157). The only effect due to greenhouse fertilizer concentration was for the WW+Uniconazole plants where the plants receiving the high greenhouse concentration were larger under the low landscape fertilizer rate. There were no differences between WW+Uniconazole and W+1 plants for any of the greenhouse or landscape fertilizer treatments, but both were smaller than the WW controls. The high landscape fertilizer rate resulted in larger plants for all greenhouse fertilizer and water treatments except the WW plants that received the high greenhouse fertilizer concentration. This data is included for informational purposes but is not as relevant a the data on changes in plant growth. Since the plants from the various greenhouse treatments were not all the same size when they were planted in the field, looking at the final overall size after 6 weeks would not give an accurate picture of what growth actually occurred in the field. The plants WW controls were actually planted into the field in this study at a larger size than they would normally be in a commercial situation. Since the goal of bedding plant establishment in the field is to have the plants fill in and touch as quickly as possible, either the WW+Uniconazole or W+1 plants would best achieve this goal under the high landscape fertilizer rate.

Table 5-11 Effect of two greenhouse fertilizer concentrations, three greenhouse water regimes and two landscape fertilizer rates on the overall plants size of Catharanthus roseus 'Cooler Peppermint' during 6 weeks in the field.

| | Overall plant size (cm)* | | | |
|---|---|---|---|---|
| | Low greenhouse fertilizer | | High greenhouse fertilizer | |
| Water regime^ | Low landscape fertilizer | High landscape fertilizer | Low landscape fertilizer | High landscape fertilizer |
| WW | 32.6 cd | 39.9 a | 35.2 bc | 37.2 ab |
| WW+ Uniconazole | 25.1 f | 31.9 d | 28.4 e | 32.4 cd |
| W+1 | 26.2 ef | 32.1 d | 27.6 ef | 33.7 cd |

* Tukey Studentized Range (HSD) Test: means within table followed by the same letter (in and between columns) are not different at P=0.05.

^ Water regime: well watered (WW); well watered with 2 mg·liter$^{-1}$ uniconazole foliar applied 3 weeks after transplanting (WW+Uniconazole); wilt maintained for 1 day prior to watering (W+1)

There was a significant two-way interaction between greenhouse fertilizer concentration and landscape fertilizer rate on shoot dry weight between 0 and 6 weeks in the field (Table 5-12). The high greenhouse fertilizer concentration caused plants with the low landscape fertilizer rate to gain more shoot dry weight than those with the high landscape fertilizer rate (26.27 versus 16.67 g for the low landscape fertilizer rate, 29.53 versus 23.55 g for the high). Similar results were reported for Lycopersicum, where increasing the amount of nitrogen (up to 300 mg liter$^{-1}$) given to seedlings in the greenhouse increased the early shoot growth in the field (Melton and Dufault, 1991a, 1991b). The greenhouse water regime produced a significant main effect on shoot dry weight between 0 and 6 weeks in the field (Table 5-12). WW plants had the greatest shoot dry weight (28.90 g), followed by WW+Uniconazole plants (22.52 g) and finally W+1 plants (20.46 g).

Table 5-12 Significance of greenhouse fertilizer concentration, greenhouse water regime and landscape fertilizer rate on shoot dry weight of Catharanthus roseus 'Cooler Peppermint' between 0 and 6 weeks in the field. Experiment 2.

| | Shoot dry weight (g) |
|---|---|
| Effect | Significant at P= |
| Greenhouse fertilizer | 0.0001 |
| Greenhouse water regime | 0.0001 |
| Greenhouse fertilizer*Water regime | 0.0549 |
| Landscape fertilizer | 0.0001 |
| Greenhouse fertilizer*Landscape fertilizer | 0.0273 |
| Water regime* Landscape fertilizer | 0.1601 |
| Greenhouse fertilizer*Water regime*Landscape fertilizer | 0.8068 |

This study demonstrated that the high greenhouse fertilizer concentration produced very little benefit over the low rate in regards to change in plant growth between 0 and 2 weeks in the field. The only benefit of the high greenhouse fertilizer concentration was for the WW plants that were grown with the low landscape fertilizer rate. This benefit was in width and size, not height. It was found that the high landscape fertilizer rate also produced very little benefit over the low rate for Catharanthus. The high rate only benefitted three of the twelve treatments, where change in width was increased. No increase in change in plant height or size was realized from the high landscape fertilizer rate during the first 2 weeks in the field. Plants treated with uniconazole in the greenhouse were found to grow less in height during the first 2 weeks in the field. Apparently, there was still some carry over effect from the chemical. Both the

WW+Uniconazole and the W+1 treatments were equally effective in increasing plant width during the first 2 weeks in the field over the WW treatment. These two treatments only increased plant size over the WW treatment when the greenhouse and landscape fertilizer rates were both low or both high.

This study also demonstrated that the high greenhouse fertilizer concentration produced very little benefit over the low rate in regards to change in plant growth between 0 and 6 weeks in the field. The only benefit of the high greenhouse fertilizer concentration was for the WW plants, which had greater width. Dufault (1986) reported Cucumis transplants conditioned with increasing nitrogen rates in the greenhouse suffered more transplant shock and grew slower than those plants conditioned with low nitrogen. The high greenhouse fertilizer concentration did produce plants with greater shoot dry weight, but this did not translate into more growth.

It was found that the high landscape fertilizer rate did produce many benefits over the low rate after 6 weeks. The high rate resulted in greater increases in plant height, width and size for all treatments except for the WW plants that received the high greenhouse fertilizer concentration. In addition to the obvious reason for this improved growth with the high fertilizer rate being an increase in the availability of nutrients to support more growth, Shimshi (1970) and Bennett et al. (1986) concluded that plants grown under higher field nitrogen rates were better able to maintain leaf turgor potential, open stomata and higher rates of individual leaf transpiration despite similar reductions in leaf water potentials during periods of low soil water availability. Even though the Catharanthus in this field study were maintained under well watered conditions, some unnoticeable water

stress very likely occurred between waterings. The effects described by Shimshi and Bennett of higher nitrogen availability could have allowed these plants to maintain more favorable internal water relations over the plants receiving the low landscape fertilizer rate, allowing photosynthesis and growth to continue at a higher rate. The high landscape fertilizer rate also increased the shoot dry weight of plants that received the low greenhouse fertilizer rate, showing that adequate fertility in the field can help overcome the effects of low fertility in production.

The greenhouse water regime was found to have no affect on changes in plant height between 0 and 6 weeks, although the WW plants did have the greatest shoot dry weight. The carry over effect of uniconazole seen after the first 2 weeks apparently wore off, allowing those plants to reach the same growth rate in height after 6 weeks as the WW and W+1 plants. After 6 weeks in the field, no significant differences in changes in width or size could be found between the WW+Uniconazole and W+1 plants. Both the WW+Uniconazole and the W+1 treatments were equally effective in increasing width and size over the WW treatment. This may have been due to the WW+Uniconazole and W+1 plants having an advantage in terms of root:shoot ratio over the WW plants. The WW+Uniconazole treatment only produced greater increases in plant size over the WW treatment under the high landscape fertilizer rate.

These findings reinforce the results of plants treated with uniconazole at week 3 reported from Experiment 1, where increasing concentrations of uniconazole, up to 4 $mg \cdot liter^{-1}$, resulted in greater increases in width and size compared to the well watered plants after 6 weeks in the field. These findings also agree with the results of moisture

stress conditioned plants reported from Chapter 4, where increasing levels of greenhouse water stress resulted in greater changes in width and size over the well watered plants after 6 weeks in the field. Both chemical growth retardants (McConnell and Struckmeyer, 1970) and moisture stress conditioning (Baser et al., 1981; Chung and Trlica, 1980; Davidson, 1969b; Evenari et al., 1977; Finn and Brun, 1980; Nash and Graves, 1993; Schwintzer, 1983; Troughton, 1960) have been proven to increase the root:shoot ratio in perennial plants. Transplants with a well developed root system ie. greater root:shoot raio recover more quickly from transplant shock (Weston and Zandstra, 1986), allowing greater growth to occur over plants with a lower root:shoot ratio.

The results of Experiment 2 suggest that Catharanthus can be grown in a greenhouse with a lower fertilizer regime such as 50 ppm N without any negative impact on plant development in the greenhouse or on landscape establishment and growth. Catharanthus should be grown with a landscape fertilizer rate of 1 lb. N/1,000 $ft^2$/available per month, rather than a lower amount, to achieve a greater increase in plant growth during the first 6 weeks in a landscape bed. Allowing 10-cm containers of Catharanthus to wilt 1 day between thorough waterings is as effective as spraying plants with 2 $mg \cdot liter^{-1}$ uniconazole 3 weeks after plug transplanting in producing compact plants of acceptable marketing size that will more quickly fill in a landscape bed than plants produced under well watered conditions. In fact, growing Catharanthus with the W+1 treatment can produce plants that are taller after the first 2 weeks in the landscape and are wider and larger after 6 weeks in a landscape bed with low fertility compared to growing the plants with the WW+Uniconazole treatment.

These two studies have shown that pretransplant nutritional conditioning, moisture stress conditioning and a commerical chemical growth retardant can be used effectively to produce both compact plants of acceptable marketing size and plants that will go on to outperform in the landscape those produced under well watered conditions with no growth retardant application. Catharanthus grown with 50 ppm N did as well in the field as those grown with 150 ppm N. Allowing a Catharanthus to wilt for 1 day between thorough waterings or foliar applying 2-4 $mg \cdot liter^{-1}$ uniconazole 3 weeks after plug transplanting were both effective in producing compact plants that went on to outgrow the well watered control plants in the landscape. The moisture stress conditioned plants showed a slight advantage over the uniconazole treated plants during the first 2 weeks in the field and in field situations were fertility was low. The high field fertilizer rate produced the greatest growth regardless of greenhouse treatment and was shown to be able to overcome the carry over effects of greenhouse-applied uniconazole after 6 weeks in the landscape.

# CHAPTER 6
# EFFECTS OF PRODUCTION WATER REGIME AND UNICONAZOLE AND RETAIL WATER REGIME ON THE LANDSCAPE PERFORMANCE OF CATHARANTHUS ROSEUS 'COOLER PEPPERMINT'

## Introduction

Most ornamental bedding plant research has focused on production issues. Recommendations for modifying production light, temperature, irrigation and growth regulators for several major species of ornamental bedding plants with the goal of improving postproduction performance were published by Armitage (1993). However, little work has evaluated effects of production practices and conditions in a retail setting on the performance of plants in an actual landscape setting.

In order to maximize growth rates, producers of bedding plants may avoid stressing plants by supplying optimum water during production. It has been standard practice, however, to reduce watering frequency at the end of production to "harden" the plants for shipping and marketing. In retail settings, plants often experience slight to severe water stress due to poor maintenance practices. Likewise, many bedding plants experience water stress upon being installed in landscape beds.

Eakes (1991a) has defined moisture stress conditioning as the controlled exposure of plants to moisture deficits during production. Moisture stress during production was reported to improve the growth and /or yield of several agronomic crops when exposed to

future moisture stress periods (Ackerson and Hebert, 1981; Brown et al., 1976; Gupta and Berkowitz, 1987; Matthews and Boyer, 1984). Petunia grown under a low-frequency irrigation regime during production was found to increase postproduction life (Armitage and Kowalski, 1983b; Armitage, 1986). The postproduction performance of these plants were evaluated in growth chambers, rather than in an actual landscape setting. Moisture stress conditioning of Salvia (Eakes et al., 1991b) and Catharanthus (Virk and Singh, 1990) was found to improve their physiological tolerance to low water potentials due to osmotic adjustment, but neither of these studies evaluated the plants' postproduction performance in a real landscape setting.

Chemical growth retardants are commonly used in the commercial production of bedding plants to produce plants that are compact, making them easier to ship and more attractive to the consumer. These growth retardants have also been shown to improve the stress tolerance of treated bedding plants in the landscape by modifying plant anatomy and/or physiology (Armitage et al., 1981; Cathey, 1975; Davis and Andersen, 1989; Seeley, 1985). However, the carry over effect of these growth retardants into a landscape setting has only recently became a concern (Davies et al., 1988; Keever and Cox, 1989; Latimer, 1991).

The purpose of this research study was to evaluate the effect of moisture stress conditioning during production, the use of a commercial chemical growth retardant (uniconazole) in the greenhouse and water stress in a retail setting on the subsequent establishment and growth of Catharanthus in an actual landscape field setting with two water regimes.

## Materials and Methods

Seedlings of Catharanthus roseus 'Cooler Peppermint' grown in 390 plug trays were shipped from Natural Beauty Greenhouses in Apopka, Florida, to Gainesville, Florida, on 6 June 1996. The 18 x 18 mm plugs were transplanted into 10-cm diameter by 8-cm deep plastic azalea containers using Vegro Clay Mix (Verlite Co., Tampa, FL) medium on 7 June. All plants were thoroughly watered and spaced on wire mesh benches in a Lexan-covered greenhouse. Since some plugs contained multiple plants, all but one plant per container were basally cut with a pair of scissors. Plants were maintained well watered and never experienced wilting conditions during the subsequent 2-week period. Liquid fertilizer derived from 20% N, 4.3% P, 16.6% K was applied at 150 ppm N with each watering during the greenhouse phase of the experiment.

On 21 June all plants were placed into a randomized, complete block design with five plants per experimental unit and three replications. The experiment was a 3 x 2 x 2 factorial with 3 greenhouse water regimes, 2 retail water regimes and 2 landscape water regimes. The three greenhouse water regimes were "WW" (plants were maintained well watered throughout the entire experiment), "W+1" (plants were allowed to wilt for one day before being watered again) and "WW+Uniconazole" (plants were maintained well watered and sprayed with 2 mg liter$^{-1}$ uniconazole on 28 June). The two retail and landscape water regimes were "WW" and "W+1".

The greenhouse production phase of the experiment was terminated on 25 July. At this time shoot and root dry weights were determined from five plants from each

greenhouse water regime treatment. Tissue was dried in a 70° C drying oven for 7 days and weighed. Root dry weight was divided by shoot dry weight to determine root:shoot ratio at the end of production. All data were subjected to analysis of variance and Tukey mean separation.

The remaining plants were placed on benches under a polyethylene covered rain shelter with open sides to simulate a retail sales area on 26 July. The two retail water regime treatments were given for 2 weeks. The average irradiance under the shelter at 1300 hours was 1220 $\mu$mol $m^{-2}$ $s^{-1}$ and the average temperature at the same time was 36.8° C.

On 7 Aug. the retail benches were removed and the research field area under the polyethylene rain shelter was prepared for the landscape portion of the study. The research field was comprised of a soil with a sand texture. Osmocote 14-14-14 (90 day release time) at the rate of 1.5 lb. N/1000 $ft^2$ (1.0 lb N supplied per month) was evenly distributed over the entire field plot area. Plants in one plot were maintained well watered while plants in the other plot were allowed to wilt between waterings. Three blocks were formed within each plot and five plants from each retail water regime were planted in each landscape water regime treatment area. The plants were spaced 12-inches apart.

Height and two widths were measured on each plant on 5 Aug., 17 Aug., 30 Aug. and 13 Sept. Average plant width was calculated by adding the two perpendicular width measurements and dividing by two. Plant size was determined by adding the average plant width and plant height, then dividing by two. The landscape portion of the study was terminated on 14 Sept. at which time all tissue above the soil line was harvested, placed in a drying oven at 70° C for one week and weighed to determine shoot dry weight. Change

in plant height, width and size was calculated for each 2-week time interval and for the entire time (6 weeks) in the landscape. All data were subjected to analysis of variance and Tukey mean separation.

## Results and Dsicussion

Greenhouse growth. Greenhouse water regime had a significant effect on root dry weight (P=0.0001), shoot dry weight (P=0.0001) and root:shoot ratio (P=0.0001) at the end of production. WW plants had the greatest root and shoot dry weights, followed by WW+Uniconazole plants and finally by W+1 plants (Table 6-1). However, the effects of water regime on root:shoot ratio was reversed, with WW and WW+Uniconazole being equal (Table 6-1).

Table 6-1 Effect of three greenhouse water regimes on root dry weight, shoot dry weight and root:shoot ratio of Catharanthus roseus 'Cooler Peppermint' after 6 weeks in production.

| | Dry Weight (g)* | | |
|---|---|---|---|
| Water Regime^ | Root Dry Weight | Shoot Dry Weight | Root:Shoot Ratio |
| WW | 0.60 a | 7.57 a | 0.079 b |
| WW+Uniconazole | 0.46 b | 5.99 b | 0.077 b |
| W+1 | 0.31 c | 3.12 c | 0.099 a |

* Tukey Studentized Range (HSD) Test: means within table followed by the same letter (in columns) are not different at P=0.01. Means calculated on 15 replicates.

^ Water regime: well watered (WW); well watered with 2 mg liter$^{-1}$ uniconazole foliar applied 3 weeks after transplanting (WW+Uniconazole); wilt maintained for 1 day prior to watering (W+1)

These results are consistent with findings by other researchers where water stress (Baser et al., 1981; Chung and Trlica, 1980; Davidson, 1969b; Evenari et al., 1977; Finn and Brun, 1980; Nash and Graves, 1993; Schwintzer and Lancene, 1983; Troughton, 1960) produced greater root:shoot ratios. These results differ with other researchers where growth retardants (McConnell and Struckmeyer, 1970) produced greater root:shoot ratios.

Landscape Growth After 2 Weeks. At 2 weeks, no significant two-way interaction between the effects of greenhouse or retail water regimes was found for change in plant height, width or size after 2 weeks in the field for either the well watered or W+1 landscape plots. For both landscape plots, greenhouse water regime by itself was significant (P=0.0005) while retail water regime had no effect on change in plant height. The greenhouse WW and W+1 plants showed equal changes in height and both changed more in height than the WW+Uniconazole plants in the well watered landscape plot. (Table 6-2). Apparently, there was some carry over effect from the greenhouse applied uniconazole. A similar effect on change in plant height in the field was reported in Chapter 5 for the WW+Uniconazole plants. For the W+1 landscape plot, the W+1 greenhouse water regime resulted in plants with the greatest increase in plant height, followed by the WW regime. The WW+Uniconazole regime resulted in the smallest changes in plant height (Table 6-3).

Greenhouse water regime by itself produced significant changes in width after 2 weeks in the field under well watered conditions (P=0.0004). The greenhouse W+1 and

WW+Uniconazole plants showed equal changes in width and both changed more in width than the WW plants (Table 6-2). Under W+1 field conditions, greenhouse water regime did not result in any changes in width. Retail water regime by itself did not produce any significant changes in width after 2 weeks in the field under well watered conditions. The WW retail plants were wider than the W+1 retail plants under W+1 field conditions (Table 6-3).

Greenhouse water regime by itself produced significant changes in plant size after 2 weeks in the field under well watered conditions (P=0.0149). The greenhouse W+1 plants showed greater changes in plant size over the WW+Uniconazole and WW plants, which had equal changes in size (Table 6-2). Greenhouse water regime did not produce any differences in change in plant size under W+1 field conditions. Retail water regime by itself did not produce any significant changes in size after 2 weeks in the field under well watered conditions. The WW retail plants were larger than the W+1 retail plants under W+1 field conditions (Table 6-3).

Table 6-2 Effect of three greenhouse water regimes and two retail water regimes on change in plant height, width and size of Catharanthus roseus 'Cooler Peppermint' between 0 and 2 weeks in the field under well watered conditions.

| | Change in plant growth (cm)* | | |
|---|---|---|---|
| Water regime^ | Height | Width | Size |
| Greenhouse | | | |
| WW | 3.62 a | 3.29 b | 3.46 b |
| WW+Uniconazole | 1.62 b | 5.16 a | 3.39 b |
| W+1 | 3.34 a | 5.70 a | 4.52 a |
| Retail | | | |
| WW | 2.78 a | 5.20 a | 3.99 a |
| W+1 | 2.94 a | 4.23 a | 3.59 a |

* Tukey Studentized Range (HSD) Test: means within table followed by the same letter (in columns and within greenhouse or retail sections) are not different at P=0.05. Means were calculated on 15 replicates.

^ Water regime: well watered (WW); well watered with 2 mg·liter$^{-1}$ uniconazole foliar applied 3 weeks after transplanting (WW+Uniconazole); wilt maintained for 1 day prior to watering (W+1)

Table 6-3 Effect of three greenhouse water regimes and two retail water regimes on change in plant height, width and size of Catharanthus roseus 'Cooler Peppermint' between 0 and 2 weeks in the field under W+1 conditions.

| | Change in plant growth (cm)* | | |
|---|---|---|---|
| Water regime^ | Height | Width | Size |
| Greenhouse | | | |
| WW | 1.52 b | 0.90 a | 1.21 a |
| WW+Uniconazole | 0.96 c | 1.76 a | 1.36 a |
| W+1 | 2.53 a | 1.34 a | 1.93 a |
| Retail | | | |
| WW | 1.82 a | 1.96 a | 1.89 a |
| W+1 | 1.51 a | 0.71 b | 1.11 b |

* Tukey Studentized Range (HSD) Test: means within table followed by the same letter (in columns and within greenhouse or retail sections) are not different at P=0.05. Means were calculated on 15 replicates.

^ Water regime: well watered (WW); well watered with 2 mg liter$^{-1}$ uniconazole foliar applied 3 weeks after transplanting (WW+Uniconazole); wilt maintained for 1 day prior to watering (W+1)

Greenhouse water regime produced greater differences in plant growth in the field during the first 2 weeks when the plants were maintained well watered in the field compared to being stressed in the field. The WW controls grew no better than either the WW+Uniconazole or the W+1 plants. The WW+Uniconazole plants did not outperform either the WW or W+1 plants. This finding is not consistent with that from Chapter 5 where plants sprayed with uniconazole greater increases in plant size during the first 2

weeks in the field compared to the untreated controls. Different field conditions may have existed. The study in Chapter 5 was undertaken in early summer while this study was done in late summer.

The W+1 plants grew either the same or more than the WW+Uniconazole and WW plants. The W+1 plants showed the greatest increase in overall size during the first 2 weeks in the field under well watered conditions and the greatest increase in plant height under W+1 conditions. These findings are consistent with the results reported in Chapters 4 and 5 for moisture stress conditioned plants. Plants that were able to reduce water loss and/or tolerate moisture stresses in the field without reducing photosynthetic capacity established more quickly (Latimer, 1990; Thomas and Latimer, 1995; Weston and Zandstra, 1986). The W+1 plants had a greater root:shoot ratio, enabling them to maintain a more optimal internal water status due to a greater water absorption capacity relative to transpirational water loss. Previous studies (Chapter 4) showed that moisture stress conditioning in the greenhouse produced Catharanthus with smaller spongy mesophyll cells which results in a greater $A^{mes}/A$ that can lead to increased photosynthesis rates and water use efficiency (LeCain et al., 1989; Patton and Jones, 1989). Catharanthus grown under greenhouse water stress were also found to have fewer stomata per leaf with a corresponding reduction in transpiration per unit leaf area, lower stomatal conductances, greater osmotic adjustment and lower turgor loss points than well watered plants (Chapter 4). The current study showed that the anatomical and physiological changes described above that occur when growing Catharanthus under water stress in the

greenhouse only gave an advantage in the landscape when plants were grown in the field without visible signs of water stress.

The plants that were maintained well watered in the retail setting grew more in width and size during the first 2 weeks in the field under W+1 conditions. Under well watered field conditions, plants grew the same during the first 2 weeks regardless of the retail water regime. These findings show the importance of maintaining proper water status of bedding plants in a retail setting if their landscape establishment is to be optimized, especially if the plants will be undergoing water stress in the field.

To best obtain the goal of having a new landscape planting of Catharanthus fill in as quickly as possible during the first 2 weeks, the plants should be produced under W+1 conditions in the greenhouse and be maintained well-watered in both the retail and landscape settings. The W+1 greenhouse water regime will not only improve landscape performance, but it will also allow a compact plant of acceptable marketing size to be produced without the use of a chemcial growth retardant, and with only a delay in flowering of 2 days over WW plants.

Landscape Growth during 6 Weeks. After 6 weeks, there was not a significant two-way interaction between the effects of greenhouse or retail water regimes for change in plant height, width or size between 0 and 6 weeks in the field under either well watered or W+1 conditions. Retail water regime was the only variable to produce an effect ($P=0.0411$) on growth rates under well watered field conditions where the WW plants produced greater changes in width over the W+1 plants (29.5 versus 26.7 cm).

Greenhouse water regime was the only variable to produce an effect (P=0.0443) on growth rates under W+1 field conditions where the W+1 and WW+Uniconazole plants grew equally in width (13.0 versus 13.3 cm), with both growing wider than the WW plants (10.8 cm).

No two-way interaction was found for overall plant size between 0 and 6 weeks in the field for either the well watered or W+1 landscape plots. Both greenhouse (P=0.001) and retail water regime (P=0.0323) produced differences under the well watered field conditions. The greenhouse WW plants were the largest (47.7 cm), with the WW+Uniconazole (39.8 cm) and W+1 (40.2 cm) plants being equal in size to each other. The retail WW plants grew larger than the W+1 plants (43.4 versus 41.8 cm). Only greenhouse water regime produced differences under W+1 field conditions (P=0.0001). The greenhouse WW plants were the largest (37.3 cm), with the WW+Uniconazole (31.3 cm) and W+1 (30.6 cm) plants being equal in size to each other. Since the greenhouse WW plants were larger than the WW+Uniconazole and W+1 plants when they were planted into the landscape beds, the change in plant size during the 6 weeks in the field would give a more accurate indication of plant growth in the field than overall plant size after 6 weeks.

No significant two-way interaction was found between the effects of greenhouse and retail water regime on final shoot dry weight between 0 and 6 weeks in the field under either field water regime. Both greenhouse (P=0.001) and retail water regime (P=0.0131) affected final shoot dry weight under the well watered field conditions. Greenhouse WW plants had the greatest shoot dry weight (47.6 g), followed by WW+Uniconazole plants

(37.7 g) and W+1 plants (31.7 g). Retail WW plants had the greater shoot dry weight over the W+1 plants (40.7 versus 37.4 g). Only greenhouse water regime had an effect on shoot dry weight after 6 weeks in the field under W+1 conditions (P=0.0001). Greenhouse WW plants had the greatest shoot dry weight (22.3 g), followed by WW+Uniconazole plants (16.6 g) and W+1 plants (13.6 g).

The increased growth rate during the first 2 weeks in the field of the W+1 and/or WW+Uniconazole greenhouse water regimes over the WW controls was not evident after 6 weeks in the field, except change in width for the greenhouse W+1 and WW+Uniconazole plants under W+1 field conditions. The increased growth rate during the first 2 weeks in the field of the WW retail water regime was not evident after 6 weeks in the field, except for width when the plants were well watered in the landscape.

The differences in plant growth between 0 and 6 weeks in the field were due most pronouncedly to the landscape water regime, where the plants grown under well watered field conditions were taller, wider, larger and with more shoot dry weight than the plants grown under W+1 field conditions. Apparently, the benefits derived from the greenhouse W+1 and retail WW water regimes assisted the plants in this study the most during the beginning of the landscape establishment period. Plants from the other greenhouse and retail water regimes were able to overcome their initial disadvantages and equal the change in plant height, width and size of the greenhouse W+1 and retail WW plants by the end of 6 weeks in the field, regardless of the landscape water regime. Because of the retail portion of this study, the plants did not experience field conditions until 2 weeks after leaving the greenhouse, unlike the plants in the studies from Chapters 4 and 5 where they

were planted in the field immediately after leaving the greenhouse. The extra 2 week retail period in this study could account for the lack of differences due to greenhouse water regime after 6 weeks in the field, which was actually 8 weeks after leaving the greenhouse. The advantages gained by the W+1 plants over the WW plants during the greenhouse phase could have dissipated by the time 8 weeks passed. This study showed that the best method for increasing the growth of Catharanthus in a landscape setting, both initially and long-term, is to grow the plants unde W+1 conditions in the greenhouse and provide adequate moisture in the growing medium in both retail and landscape settings.

# CHAPTER 7
# CONCLUSIONS

Based upon United States Department of Agriculture data (USDA, 1996), bedding and garden plants comprise the largest and most rapidly expanding sector of the $3.17 billion floriculture market, accounting for 44 percent of the 1996 floriculture production. This amount represents a 9-percent increase from 1990.

This upward trend in bedding and garden plant production and sales can be explained by a growing gardening population, greater accessibility of these plants by the public because of mass merchandisers, improved advertising, a greater product selection due to breeding efforts and by production of a quality product. Improved postproduction performance of bedding and garden plants in retail and landscape settings should be a part of the above list. Consumers tend not to make repeat purchases of items that did not perform well, regardless of the reason for this poor performance. Therefore, efforts to improve the performance of bedding plants as they pass from production to retail to landscape settings would improve consumer satisfaction and could generate more repeat business for growers and retailers.

There were no effects due to production light levels on growth of Catharanthus either after two or six weeks in the landscape. The lack of differences in field growth may be due to the fact that the two light levels did not produce plants with differences in total

stomata per leaf, transpiration per unit leaf area or turgor loss points, all factors that have a great influence over plant water status, photosynthetic capacity and ultimately plant growth. Since these two production light levels were found to neither help nor hinder the establishment of Catharanthus in the field under well watered conditions, this study revealed that some leeway exists as to what light levels may be used for growing Catharanthus if postproduction performance is a concern.

This study showed that Catharanthus can be grown under lower fertility rates (50 ppm) than industry standards for other bedding plants (150 ppm N with each watering; Armitage, 1993) without any negative effect on landscape establishment and growth. The high fertilizer rate (150 ppm ) did produce plants with more shoot dry weight after 6 weeks in the field, but this did not translate into larger plants. The high landscape fertilizer (1.5 lbs. N/1,000 $ft^2$) rate produced the largest plants after 6 weeks in the field, regardless of the greenhouse fertilizer rate or water regime. The high rate of field fertilizer was found to be particularly necessary for plants treated with uniconazole to equal the performance of the W+1 plants after 6 weeks in the field.

Increasing levels of water stress in the greenhouse resulted in greater changes in plant height, width and size after both 2 and 6 weeks in the field. Since there was not a significant difference between the W+1 and W+3 treatments, it was suggested that the W+1 treatment be used so as not to delay greenhouse flowering and/or size without realizing any added benefit in the postproduction performance. Moisture stress conditioned plants developed greater root:shoot ratios than both uniconazole treated plants and the untreated WW plants. Increasing greenhouse water stress resulted in

smaller spongy mesophyll cells and a corresponding greater $A^{mes}/A$, fewer stomata per leaf, lower transpiration per unit leaf area and lower stomatal conductances. Moisture stressed conditioned plants were found to osmotically adjust which allowed for turgor loss points to occur at lower water potentials for these plants. When both anatomical and physiological changes were considered, the W+1 plants had a greater potential advantage in terms of tolerating future water stresses over the LW+1 plants. Increasing water stress during production also delayed flowering and reduced flower size. W+1 plants flowered 2 days later than the WW controls, and flowers averaged 0.5 cm less in diameter. This delay in flowering and reduction in flower size would be of minor importance at a commercial level.

Uniconazole sprayed at 2 or 4 mg $liter^{-1}$ 3 weeks after plug transplanting and the W+1 water stress treatment were equally effective in producing a compact plant of acceptable commercial size and quality. Rather than inhibiting the establishment and growth of Catharanthus in the landscape due to a carry over effect, this uniconazole concentration and time of application was found to enhance field growth compared to untreated plants, beginning 2 weeks after planting into the field and continuing up to 6 weeks after planting. This improved growth was attributed to the treated plants having a smaller total leaf area compared to the untreated controls which gave them an advantage in the field by reducing whole plant transpiration relative to water absorbing capacity.

Applying uniconazole at the very end of the greenhouse production cycle was found to inhibit the establishment and growth of Catharanthus in the landscape, especially during the first 4 weeks in the field. It appeared that the efficacy of uniconazole on Catharanthus

at the concentrations used in this study lasted between 3 and 4 weeks. Thus, if a grower wants to produce Catharanthus that is both compact and will quickly establish in the landscape, this study found that uniconazole should be foliar applied 3 to 4 weeks before shipping at a concentration between 2 and 4 mg liter$^{-1}$. The exact concentration would depend on an individual grower's production environment and targeted finished plant size.

The final experiment demonstrated that the best way to have a new landscape planting of Catharanthus fill in as quickly as possible during the first 2 weeks is to produce the plants under W+1 conditions in the greenhouse and maintain them well watered in both the retail and landscape settings. The advantages in growth during the first 2 weeks in the field for the W+1 and/or WW+ Uniconazole treatments were not present after 6 weeks in the field. No differences in plant spatial growth after 6 weeks were attributed to greenhouse water regime. The differences in plant growth after 6 weeks were primarily due to the landscape water regime, where the WW plants were taller, wider, larger and had more shoot dry weight than the W+1 plants. Apparently, the benefits derived from the greenhouse W+1 and retail WW water regimes assisted the plants the most during the beginning of the landscape establishment period. This experiment found that the best method for increasing the growth of Catharanthus in a landscape setting, both initially and long-term, is to provide adequate moisture in the growing medium in both retail and landscape settings.

Bedding plant producers not only need to quickly produce compact plants that ship easily and are attractive to the consumer, but that will also perform well in less than ideal retail and landscape settings. This research project has shown that how a plant is grown

can affect its anatomy and physiology, which will either help or hinder its postproduction performance. The research showed that Catharanthus roseus 'Cooler Peppermint' performed better when fertilized with 50 ppm N from beginning to end of production, given a water regime consisting of one day of wilting between thorough waterings that is initiated 2 weeks after plug transplanting, maintained well watered in the retail setting and planted in a landscape bed that is maintained well watered and receives 1.0 lb. N/1,000 $ft^2$/month. If a chemical growth retardant is to be used in lieu of the water stress regime, results of these studies suggest that uniconazole between 2 and 4 mg $liter^{-1}$ be foliar applied 3 weeks after plug transplanting.

With the continued efforts of plant breeders, more studies evaluating the effects of production practices on postproduction performance and an increased commitment of retailers to maintaining their plant inventories in good condition, consumers of ornamental bedding plants will have a greater variety of plant material available that will meet or exceed their expectations. This satisfaction will only continue to drive the demand and production of bedding and garden plants upward.

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## BIOGRAPHICAL SKETCH

Brent Maynard Chapman was born in Kankakee, Illinois, on November 17, 1962. He grew up on a farm where corn, soybeans, wheat and swine were raised. His participation in 4-H and FFA activities occupied much of his time during elementary and secondary school. After graduating from Herscher High School, he attended Kankakee Community College for three semesters before transferring to the University of Illinois in Champaign-Urbana. A Bachelor of Science degree in ornamental horticulture with a specialization in landscape design was earned in May, 1984.

After working in the horticulture industry in St. Louis, Missouri, as a landscape designer and assistant greenhouse grower, he returned to college to earn a Master of Science degree in horticulture from Virginia Tech in Blacksburg, Virginia. His thesis looked at environmental manipulations that may improve the marketabiltiy of Abutilon as a flowering potted plant. After graduating in June, 1987, he accepted a full-time position at Lake City Community College in Lake City, Florida, teaching landscape management.

In the fall of 1990, he began postbaccalaureate studies in botany at the University of Florida in Gainesville, Florida. Part-time work leading to a Ph.D. in environmental horticulture was begun with Dr. James E. Barrett in the fall of 1991. Upon completion of this degree, the author will return to his full-time horticulture teaching position at South Puget Sound Community College in Olympia, Washington.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

James E. Barrett, Chair
Professor of Horticulture Science

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Terril A. Nell
Professor of Horticulture Science

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Edward F. Gilman
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